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LOS ANGELES AND LONG BEACH HARBORS MODEL STUDY: REPORT 6. RESON--ETC(U)
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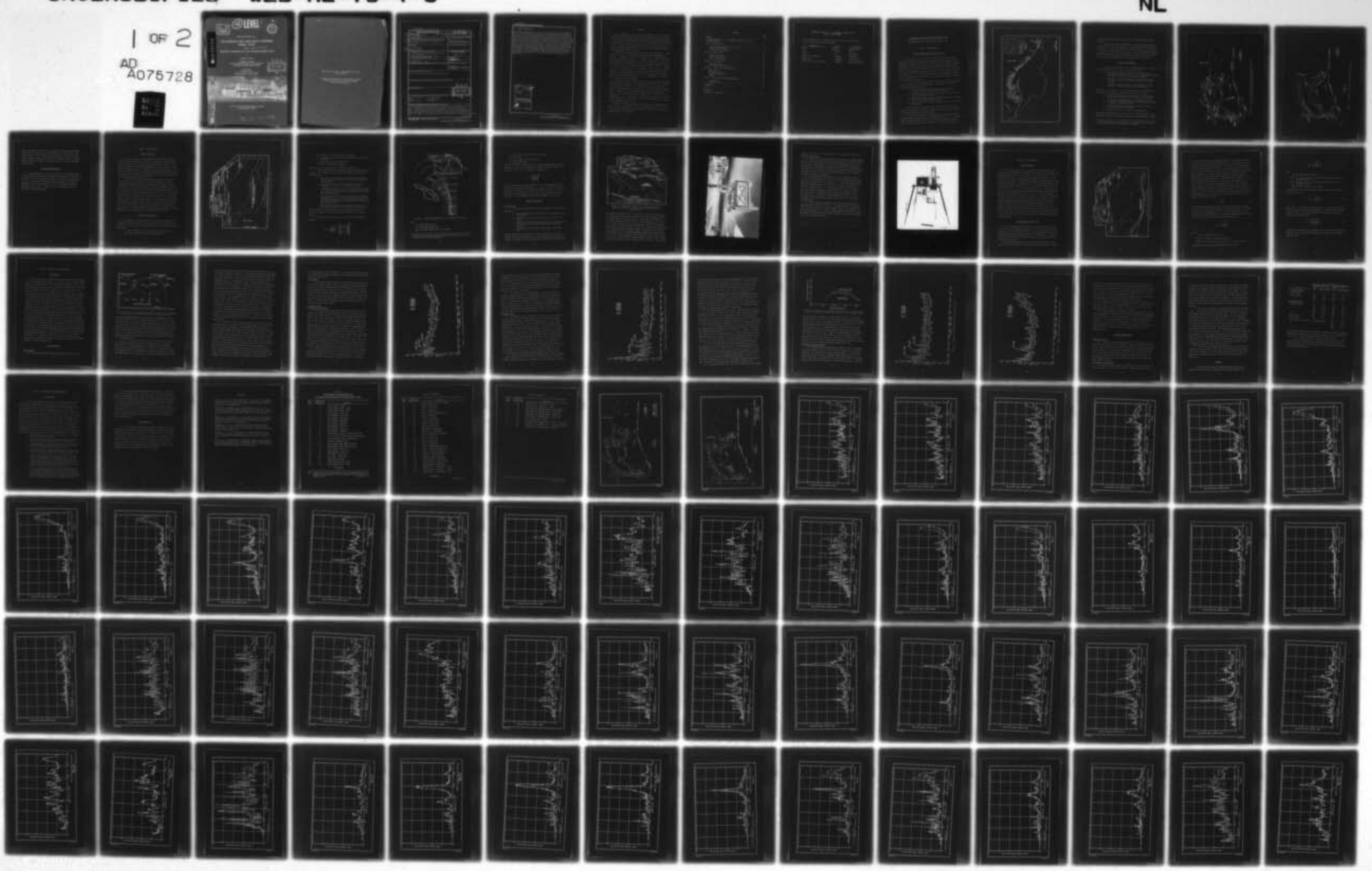

(12) LEVEL II

TECHNICAL REPORT H-75-4

LOS ANGELES AND LONG BEACH HARBORS MODEL STUDY

Report 6 (Rept. 5, AD16904)

RESONANT RESPONSE OF THE MODIFIED PHASE I PLAN

by

Douglas G. Outlaw

Hydraulics Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

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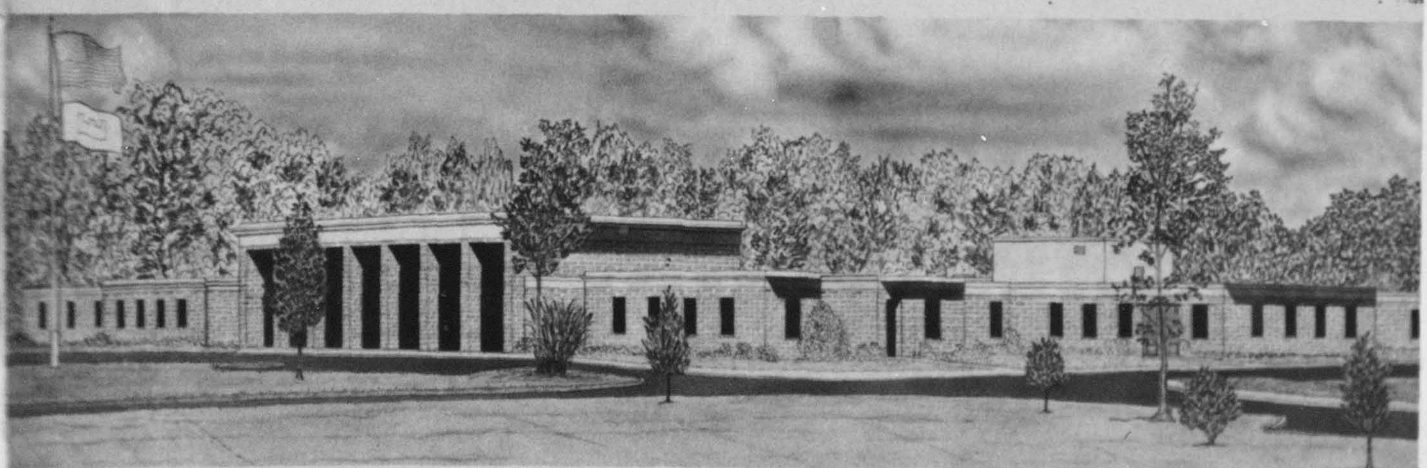

Prepared for U. S. Army Engineer District, Los Angeles
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REPORT DOCUMENTATION PAGE

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9

1. REPORT NUMBER
Technical Report H-75-4

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

14 WES-HL-75-4-6

6

4. TITLE (and Subtitle)
LOS ANGELES AND LONG BEACH HARBORS MODEL STUDY; Report 6. RESONANT RESPONSE OF THE MODIFIED PHASE I PLAN

5. TYPE OF REPORT & PERIOD COVERED
Report 6 of a series

6. PERFORMING ORG. REPORT NUMBER

10

7. AUTHOR(s)
Douglas G. Outlaw

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U. S. Army Engineer Waterways Experiment Station
Hydraulics Laboratory
P. O. Box 631, Vicksburg, Miss. 39180

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

12 139

11. CONTROLLING OFFICE NAME AND ADDRESS
U. S. Army Engineer District, Los Angeles
P. O. Box 2711
Los Angeles, Calif. 90053

11

12. REPORT DATE
Aug[illegible]979

13. NUMBER OF PAGES
134

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

DDC
RECEIVED
OCT 30 1979
B

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Harbor oscillations	Long Beach Harbor
Harbors	Los Angeles Harbor
Hydraulic models	Water waves

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A study of harbor resonance due to long-period wave excitation was conducted in the Los Angeles and Long Beach Harbors hydraulic model for the Modified Phase I improvement plan and compared with resonant response for existing conditions. Proposed improvements for the Modified Phase I plan included dredging of navigation channels and an associated landfill of approximately 200 acres in the Port of Los Angeles, and an Outer Harbor Oil Terminal in the Port of Long Beach. Cont

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411 389

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20. ABSTRACT (Continued).

Wave periods ranging from 15.5 to 410 sec with incident direction of approach from the south were included in the study. Previous refraction studies had shown that due to offshore topography, Los Angeles and Long Beach Harbors are well protected from all incident long-period wave directions, except from the south. Results of the study show wave-height amplification, periods of maximum response, and modes of oscillation for various berthing areas. Comparisons of model data for existing conditions and the proposed plan indicated that resonant modes of oscillation in the existing harbor berthing areas were not substantially altered. With the Modified Phase I plan, periods of maximum resonant amplification in existing harbors generally shifted slightly. Resonant peaks in the amplification data generally decreased or increased slightly. For existing conditions, periods of maximum response agreed closely with prototype measurements. In the proposed Outer Harbor Oil Terminal, modes of oscillation either resulted in antinodes in the berthing areas or had relatively low amplification.

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PREFACE

The Los Angeles and Long Beach Port Authorities plan to construct additional harbor basins and dredge deeper channels and harbor areas to meet growing future demands for expansion of ship mooring facilities. In this report, the sixth in a series to be published under the general title "Los Angeles and Long Beach Harbors Model Study," the results of a harbor resonance study conducted in the Los Angeles and Long Beach Harbors hydraulic model are given.

Project administration and funding were provided by the U. S. Army Engineer District, Los Angeles (SPL), under project management of Messrs. J. Chapman, H. Converse, T. Nizinski, and D. Muslin and under the general direction of Messrs. G. Fuquay, former Chief of the Engineering Division, T. Nishihara, Chief of the Engineering Division, and C. H. Fisher, Chief of the Coastal Resources Branch. COL R. J. Malley, CE, COL J. V. Foley, CE, COL H. G. Robinson, CE, and COL G. A. Teague, CE, were District Engineers of SPL during the course of this study. General project administration for the U. S. Army Engineer Division, South Pacific, was provided by Messrs. O. F. Weymouth, O. T. Magoon, J. W. Gerhart, and A. E. Wanket.

The model study was conducted by the U. S. Army Engineer Waterways Experiment Station (WES), in the Hydraulics Laboratory, under the general supervision of Messrs. H. B. Simmons and F. A. Herrmann, Jr., Chief and Assistant Chief, respectively, of the Hydraulics Laboratory; Dr. R. W. Whalin, Chief of the Wave Dynamics Division, and Mr. C. E. Chatham, Chief of the Wave Processes Branch (WPB). This report was prepared by Mr. D. G. Outlaw, WPB. The model wave tests were conducted by Mr. Outlaw with the assistance of Messrs. K. A. Turner, L. A. Barnes, and W. Reynolds and Ms. J. Jones.

Directors of WES during the model design and the preparation and publication of this report were BG E. D. Peixotto, CE, COL G. H. Hilt, CE, COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4046.856	square metres
feet	0.3048	metres
inches	25.4	millimetres
miles (U. S. statute)	1.609344	kilometres
square feet	0.09290304	square metres
square miles (U. S. statute)	2.589988	square kilometres

LOS ANGELES AND LONG BEACH HARBORS MODEL STUDY

RESONANT RESPONSE OF THE MODIFIED PHASE I PLAN

PART I: INTRODUCTION

Background and Model Study Objectives

1. Historically, the ports of Los Angeles and Long Beach have experienced long-period surge activity which sometimes causes mooring problems for ships berthed in some locations within the harbors complex. Development of the harbors and past resonance characteristics of the harbors have been reviewed in detail as a portion of a study[1] completed by Science Engineering Associates for the U. S. Army Engineer District, Los Angeles. The ports are located on San Pedro Bay along the southern coast of California. A location map and the existing harbor configuration are shown in Figure 1.

2. The model investigation reported herein was conducted as a part of the Los Angeles and Long Beach Harbors study which included the following four major objectives:

- a. Determine the incidence and severity of troublesome oscillations in the present harbor complex.
- b. Investigate the tidal circulation characteristics of the present and proposed harbors.
- c. Determine the optimum plan for future expansions to provide safe and economical berthing areas.
- d. Analyze the effect proposed expansions will have on existing harbors.

3. Prototype wave, tide, and ship motion data[2,3] were acquired over a 1-yr period in the harbor. Analyses of prototype wave and ship motion data are described in Reference 4.

4. In the existing harbors, troublesome ship mooring conditions are occasionally experienced in East Channel of the Port of Los Angeles and in Southeast Basin of the Port of Long Beach, along the edge of Pier J, and near the west end of Basin 6. The location of the city

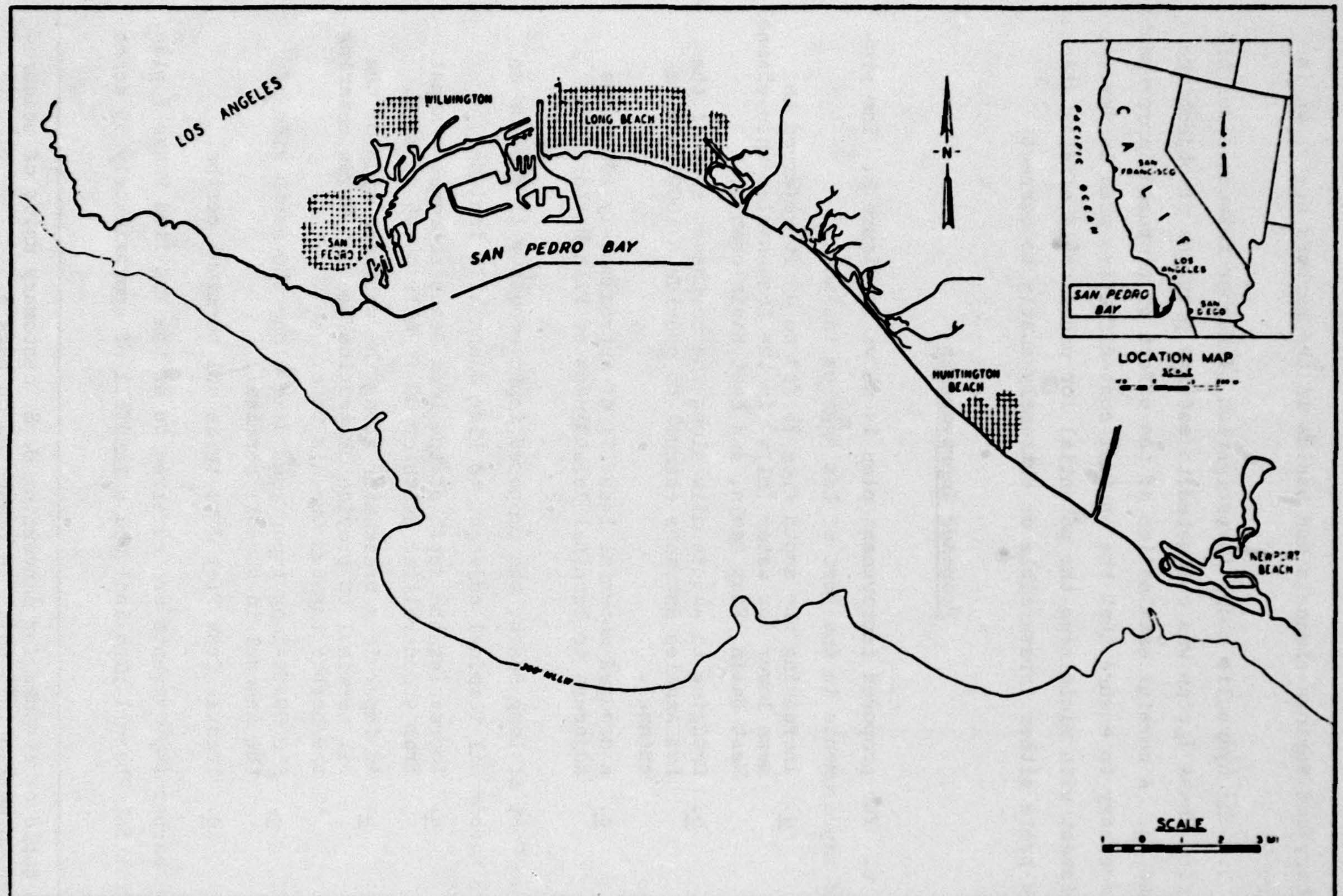

Figure 1. Site map

boundary and various channels and basins in the harbors are shown in Figure 2.

5. The hydraulic model investigation of harbor resonance for the Modified Phase I plan was conducted to satisfy portions of objectives 2c and 2d. A careful examination of the effect of proposed improvements is necessary to ensure that the optimal cost-effective plan is developed consistent with minimizing the potential for undesirable effects which could prove either irreversible or extremely costly to correct.

Proposed Improvements

6. The proposed improvement plan is shown in Figure 3. The proposed improvements in the Port of Los Angeles include:

- a. Increasing the depth from 35 ft* to 45 ft referred to mean lower low water (mllw) in the Los Angeles main channel, West Basin, East Basin, and East Basin channel.
- b. Dredging to -45 ft mllw along the northeast side of the Los Angeles entrance channel to provide a 1000-ft-wide channel.
- c. A dredged material landfill of approximately 200 acres adjacent to Terminal Island east of Fish Harbor.

In the Port of Long Beach, the proposed improvements will provide an Outer Harbor Oil Terminal adjacent to Pier J and will include:

- a. Increasing the depth of the Long Beach entrance channel from a controlling depth of 60 ft mllw to 65 ft mllw.
- b. An impervious breakwater along the southern side of the oil terminal to provide protection against waves entering the harbor through Queen's Gate.
- c. A 2000-ft-long impervious dike along the north side of the channel in the oil terminal.
- d. Trestle from Pier J to three oil terminal berths.

Those harbor improvements are referred to as the Modified Phase I plan. The initial Phase I plan included a landfill of approximately 55 acres

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

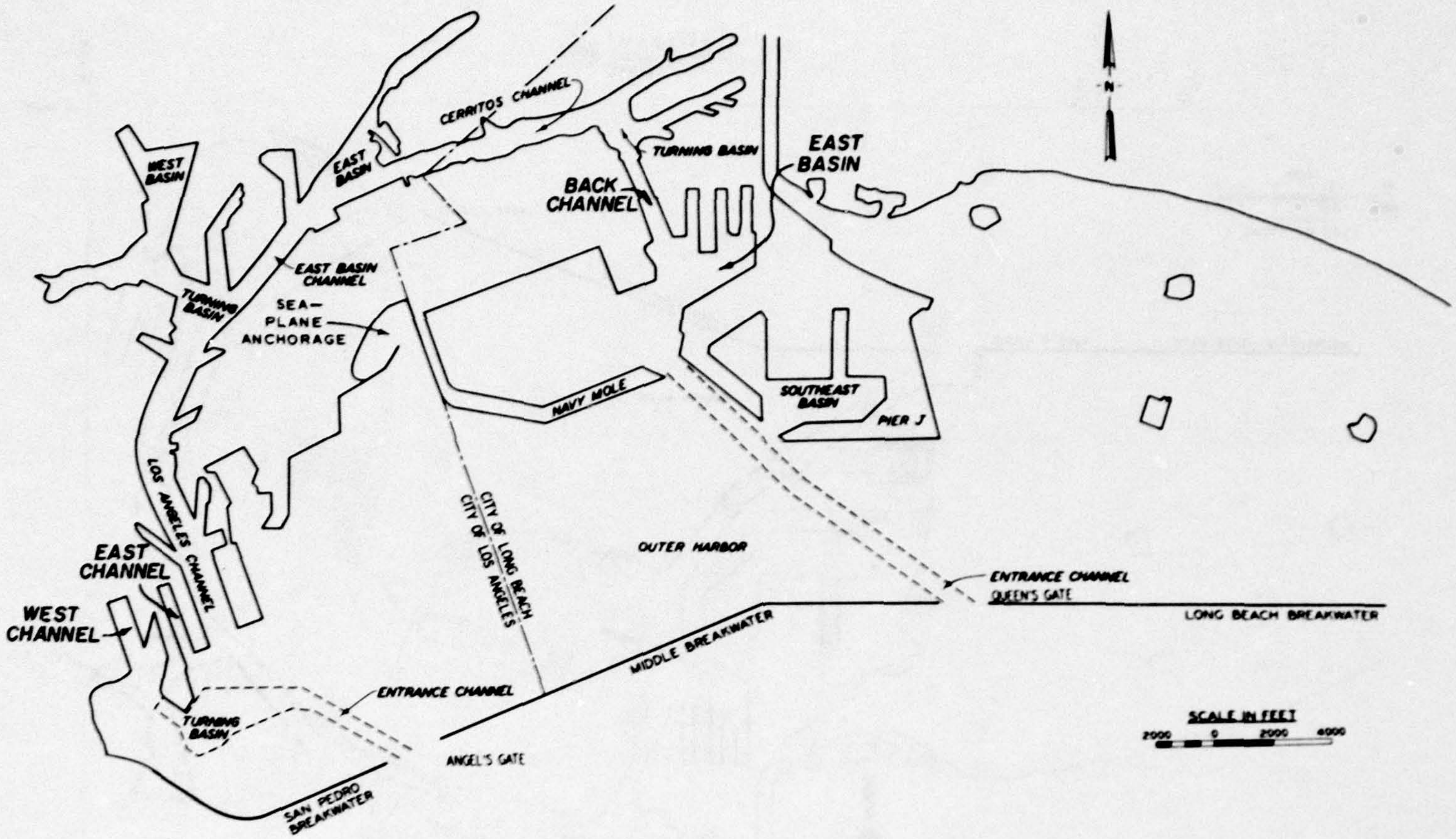

Figure 2. Location of city boundary and various channels and basins in the Los Angeles and Long Beach Harbors

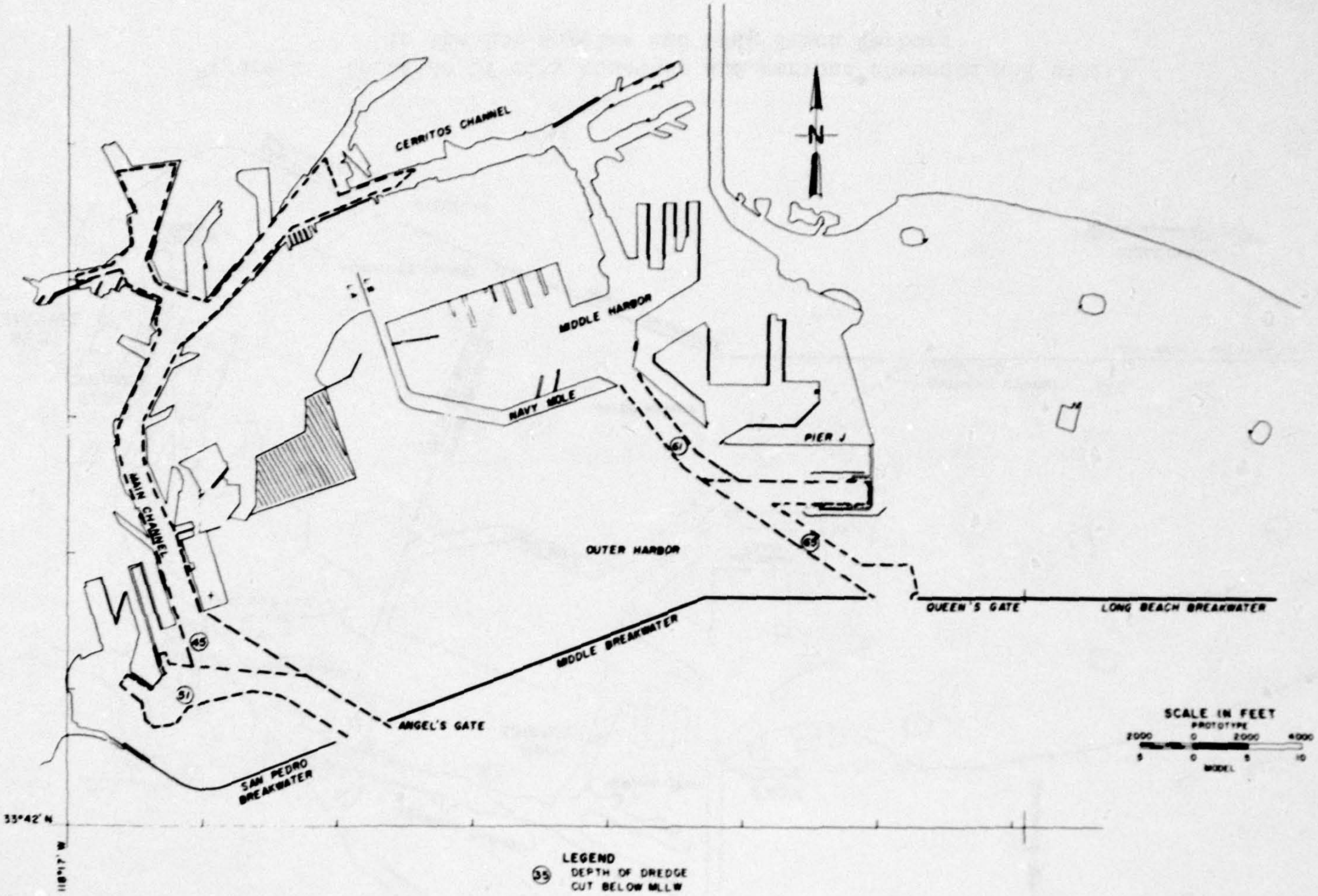

Figure 3. Elements of the proposed Modified Phase I plan

near the northwest tip of Pier J as a part of the proposed Long Beach Outer Harbor Oil Terminal, but this landfill was not included in the Modified Phase I plan. Element 6c, the 2000-ft-long dike, was added after a strong cross-channel oscillation developed in the oil terminal during initial wave tests of the Phase I plan at a period of approximately 2 min.

Associated Model Tests

7. An investigation of tidal circulation for the Modified Phase I plan was started in the hydraulic model after completion of the wave test series. A two-dimensional breakwater stability study sponsored by the Port of Long Beach for design of the Outer Harbor Oil Terminal breakwater also was conducted at the U. S. Army Engineer Waterways Experiment Station (WES). Results of these investigations will be published in separate reports.

PART II: MODEL DESIGN

Model Description

8. The Los Angeles and Long Beach Harbors hydraulic model was molded in concrete grout and accurately reproduced to scale San Pedro Bay and a portion of the Pacific Ocean surrounding the harbor. The model shoreline extended from approximately 2 miles northwest of Point Fermin to Huntington Beach. Underwater contours were reproduced out to the -300 ft mllw contour, and sufficient additional offshore area was included to provide space for wave generators and the model tide generator. Model limits are shown in Figure 4.

9. The model was constructed to linear scale ratios, model to prototype, of 1:100 vertically and 1:400 horizontally. The model covered approximately 44,000 sq ft, representing 253 square miles of prototype area. Depth data for model contours were obtained from the U. S. Coast and Geodetic Survey (now National Ocean Survey) Charts 5101 and 5147, and from harbor soundings provided by the Ports. Major piers and wharves were reproduced in the model with 1/16- and 1/32-in.-diam brass rods used to simulate pier piling. The bays east of the harbors such as Alamitos Bay and Anaheim Bay were correctly reproduced in plan but depths were averaged in the model in order to expedite construction and, at the same time, to permit proper reproduction of approximate tidal prisms. If future studies in these areas are required, the actual bathymetry can be installed in the model with relative ease.

Design Considerations

10. Comprehensive investigations of the following items were conducted during model design to aid in selection of proper model scales and limits in order to ensure accurate reproduction of long-period wave excitation.

<u>a</u>. Wave refraction for wave periods of 15 sec to 6 min.

<u>b</u>. Energy transmission through the breakwaters.

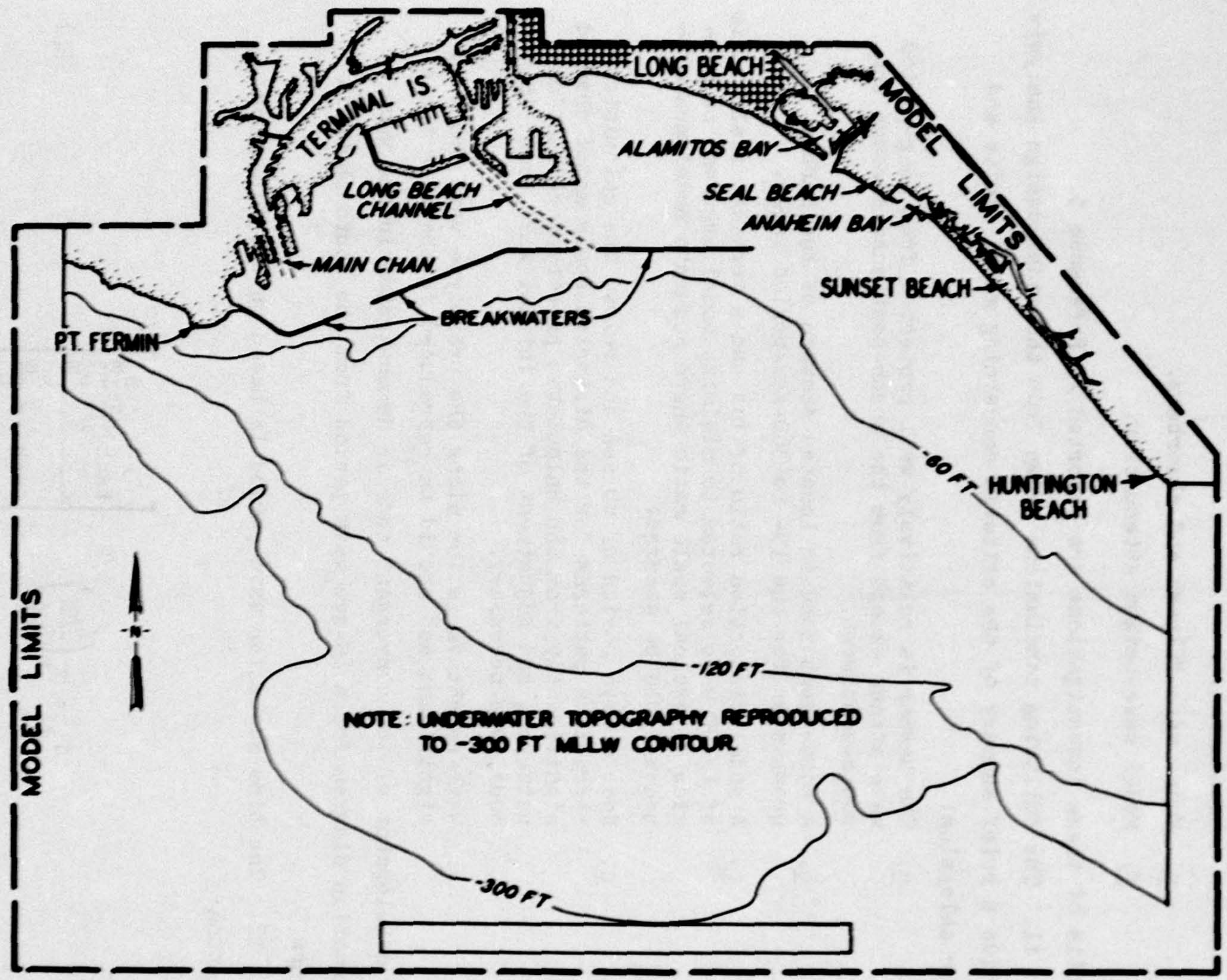

Figure 4. Los Angeles and Long Beach Harbors model

c. Diffraction through the harbor entrances.

d. Reflection from the offshore topography and from harbor boundaries.

e. Model wave filters and absorbers.

f. Model wave-height attenuation.

Details of these investigations are reported in Reference 5.

11. The following conclusions drawn from the model design analysis provide a brief summary of the criteria concerning model limits and scale selection:

a. The harbor is relatively well protected from long-period wave attack except from the south-southeast through the south-southwest.

b. A convergent zone is located seaward of the harbor breakwater for the 15- to 360-sec-period range.

c. A model distortion ratio of 1:4 and a vertical scale ratio of 1:100 were selected to minimize model area and to provide a vertical scale ratio where accurate model measurements could be assured.

d. Near a wave period of 60 sec and below, the calculated refraction patterns for the distorted scale model changed significantly from the calculated prototype refraction patterns, and adjustment of the initial wave front in the model was necessary.

e. Wave-height variation along the prototype wave front is significant and should be reproduced in the wave tests.

The development of the convergent zone is demonstrated in the wave refraction diagram for a 60-sec wave period from the south shown in Figure 5.

12. The time scale for wave period is based on the following equation:

$$T_m = T_p\left(\frac{\ell_{hm}}{\ell_{hp}}\right)^{1/2}\left[\frac{\tanh \frac{2\pi}{\Omega}\frac{h_m}{L_m}}{\tanh 2\pi \frac{h_m}{L_m}}\right]^{1/2} \qquad (1)$$

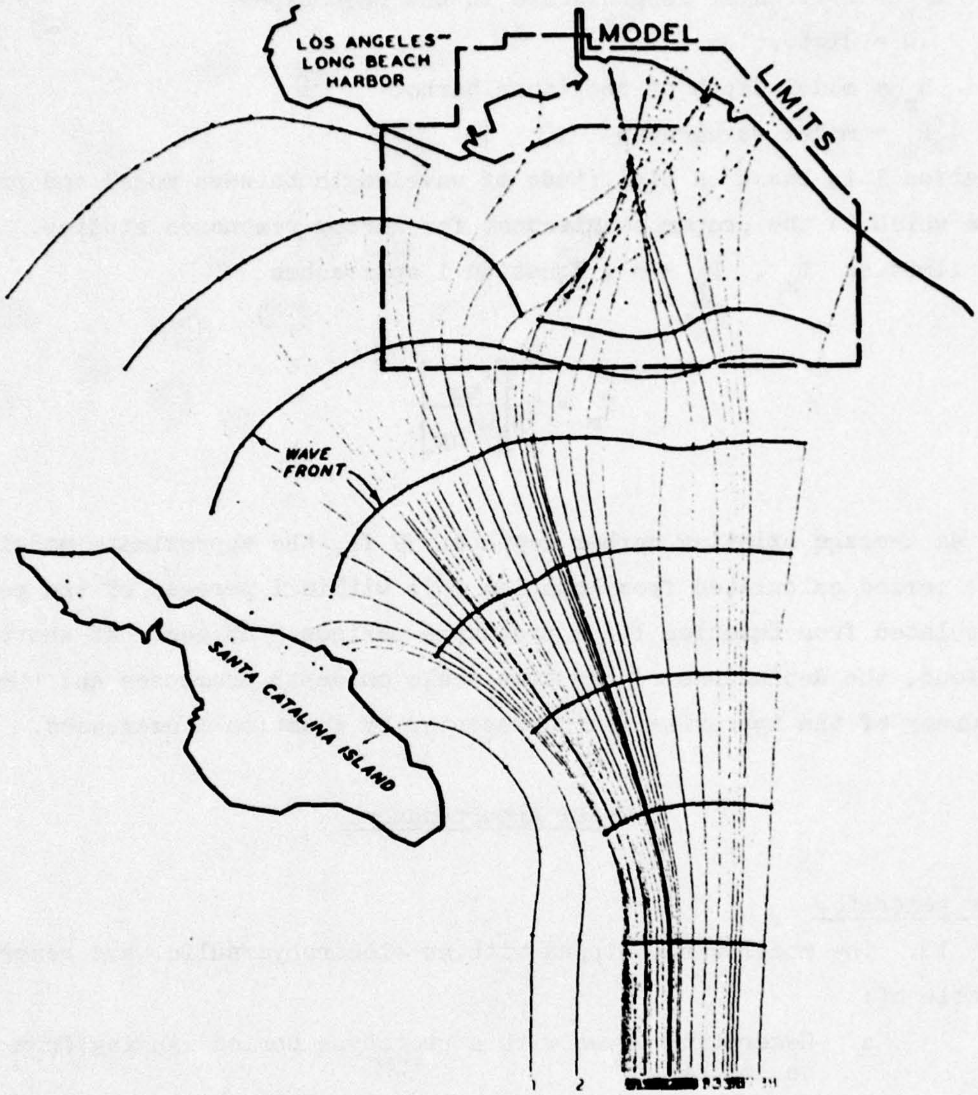

Figure 5. Refraction diagram for 60-sec wave from the south

where

T_m = model wave period*

T_p = prototype wave period

ℓ_{hm} = horizontal length scale in the model

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* For convenience, symbols and unusual abbreviations are listed and defined in the Notation (Appendix A).

ℓ_{hp} = horizontal length scale in the prototype

Ω = distortion

h_m = model depth of the inner harbor

L_m = model wavelength

Equation 1 is based on similitude of wavelength between model and prototype which is the proper requirement for harbor resonance studies. In the limit as L_m , $L_p \to \infty$, Equation 1 approaches

$$T_m \simeq T_p \left[\frac{\ell_{hm}}{\Omega \ell_{hp}} \right]^{1/2} \qquad (2)$$

For an average existing harbor depth of 39 ft, the approximate model wave period calculated from Equation 2 is within 1 percent of the period calculated from Equation 1 for prototype periods $\geq$ 85 sec. At shorter periods, the dependence of the time scale on depth increases and the accuracy of the approximation represented by Equation 2 decreases.

Model Appurtenances

Wave generator

13. The model was equipped with an electrohydraulic wave generator capable of:

- a. Generating waves with a prototype period ranging from 15 to 360 sec.
- b. Generating a wave with small variation in period and height.
- c. Defining resonant response occurring over a narrow period band by controlling the model wave period with great precision.
- d. Generating a variable wave height along a curved wave front.

The wave generator was composed of 14 units, each with a 15-ft wave paddle, for a total length of 210 ft. The 15-ft sections may be positioned to approximate a curved wave front, as indicated in Figure 6 for

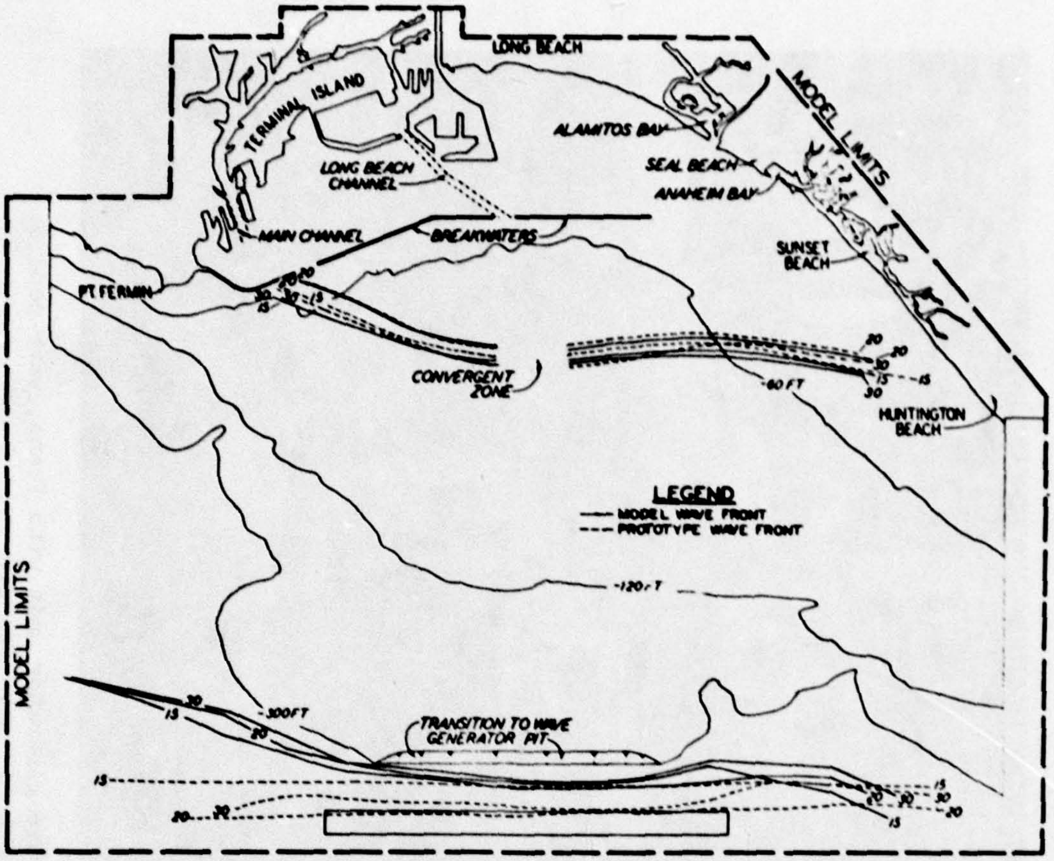

Figure 6. Comparison of model and prototype wave fronts near the -300 ft mllw contour and near the harbor at 15, 20, and 30 sec

prototype wave periods of 15, 20, and 30 sec. The initial prototype and adjusted model wave-front locations are shown along with a comparison of wave-front locations for each of the wave periods seaward of the harbor breakwater after formation of the convergent zone. A 15-ft unit of the wave generator with the frame, wave paddle, and hydraulic power supply is shown in Figure 7. Each unit is independently controlled from a computer-generated command signal. Performance tests indicate that each unit will consistently maintain a peak-to-peak stroke error of less than 1 percent and that the maximum phase lag variation between any 2 of the 14 units from the command signal is 4 deg or less. Variation in the generated period is negligible for each unit. The detailed

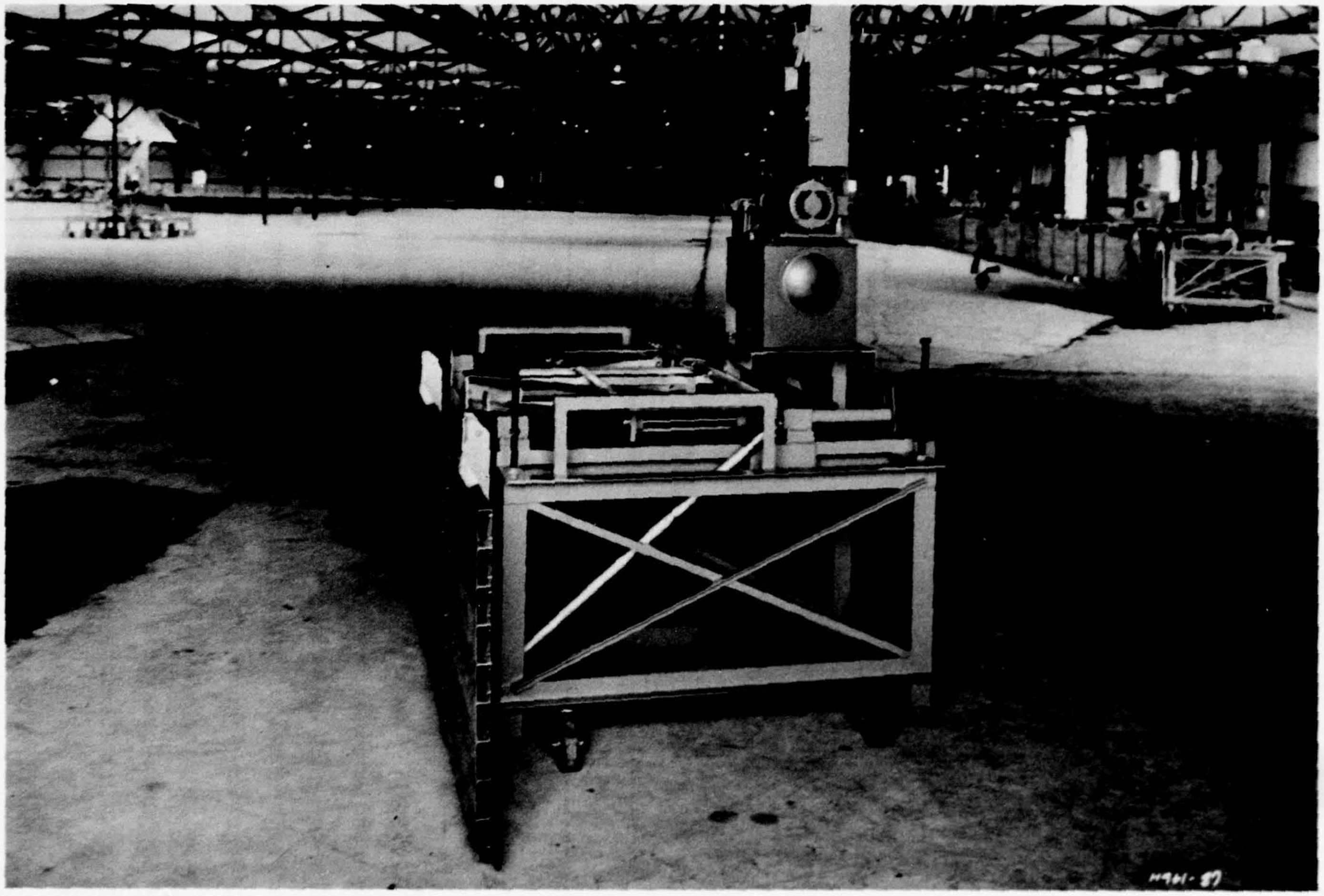

Figure 7. Electrohydraulic wave generator unit with frame, wave paddle, and hydraulic power supply

design and operation of the wave generator is discussed in Reference 5.

Wave data acquisition

14. Wave data acquisition in the Los Angeles and Long Beach Harbors model is controlled[5] by an automated data acquisition and control system (ADACS) due to the complexity, large size, and magnitude of model wave data required. The ADACS configuration consists of four subsystems: (a) digital data recording and controls, (b) analog recorders and channel selection circuits, (c) wave and interfacing equipment, and (d) wave generators and control equipment.

15. The digital data recording and control subsystem is built around a 32K minicomputer with 16-bit words of core memory and a 1-μsec cycle time. Peripheral devices include a 1.1 million word moving head disc and a magnetic tape controller with two 9-track tape units for data and software storage. A teletype unit serves as the master console and a matrix electrostatic printer/plotter is used for output. Data acquisition is automatic without operator intervention once a wave test begins. The analog recording subsystem consists of five 12-channel oscillographs and provides a visual record of the analog wave-gage signal.

16. The wave gages are parallel wire, water-surface-piercing, resistance gages as shown in Figure 8. The gage measures the conductance of water between two vertical parallel wires. The conductance is directly proportional to the depth of submergence of the parallel wires. The gages can accurately detect changes in model water-surface elevation of 0.001 ft (prototype 0.10 ft).

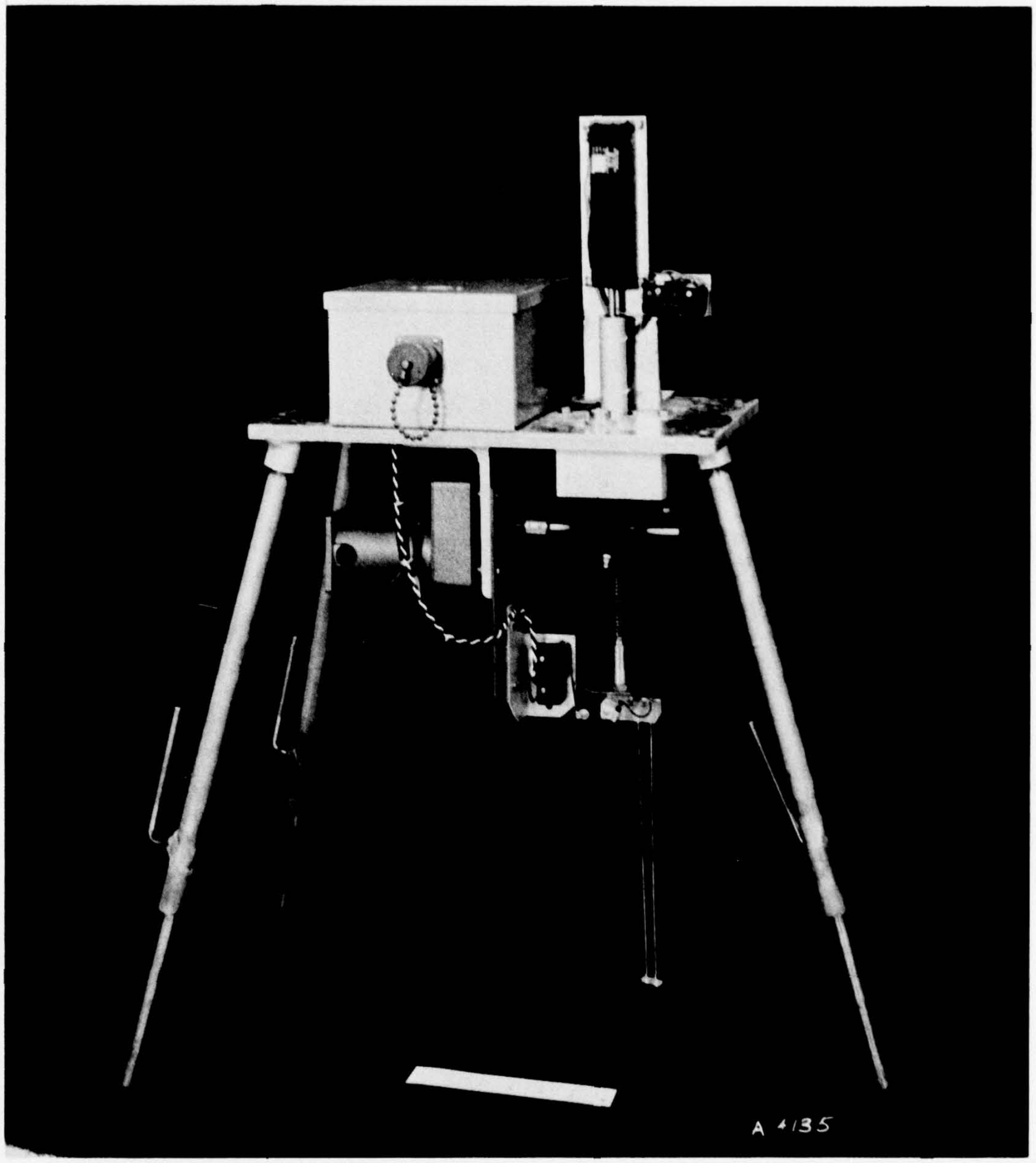

Figure 8. Parallel rod wave gage

PART III: DATA ANALYSIS

Test Conditions

17. Tests were conducted for long-period waves approaching the continental shelf seaward of the harbor from the relatively narrow long-period energy window[1,5] centered around the south direction. Figure 9 illustrates the wave generator position computed in Reference 5 for various period ranges. Normalized wave-height variations along the wave front were simulated in accordance with the model design refraction data. A maximum prototype wave height of 4 ft at the generated wave front was used in the 15.4- to 150.0-sec prototype period range. Between 150 sec and 280 sec, a 3-ft maximum prototype wave height was used, while above 280 sec a 2-ft maximum wave height was used. The variation in wave height over these period ranges was necessary to decrease the magnitude of strong resonant oscillations and minimize finite amplitude effects on wave characteristics while maintaining sufficiently large model waves to obtain accurate model measurements throughout the area of interest. The still-water level during the test series was +2.8 ft mllw and the wave period interval between tests varied from 0.5 sec to 5.0 sec (prototype). Smaller period increments between wave tests were used in the lower period range to ensure accurate definition of sharp resonant peaks.

Wave-Height Amplification

18. The significant wave height (H_s) at each gage location was calculated from the digital wave record (24 to 60 recorded cycles) and corrected for model scale effects due to internal and bottom friction during propagation from the wave generator to the harbor. A detailed discussion of the relatively small correction for viscous attenuation is given in Reference 5.

19. Wave-height amplification is traditionally defined as the ratio of the wave height at a particular location in a harbor to twice

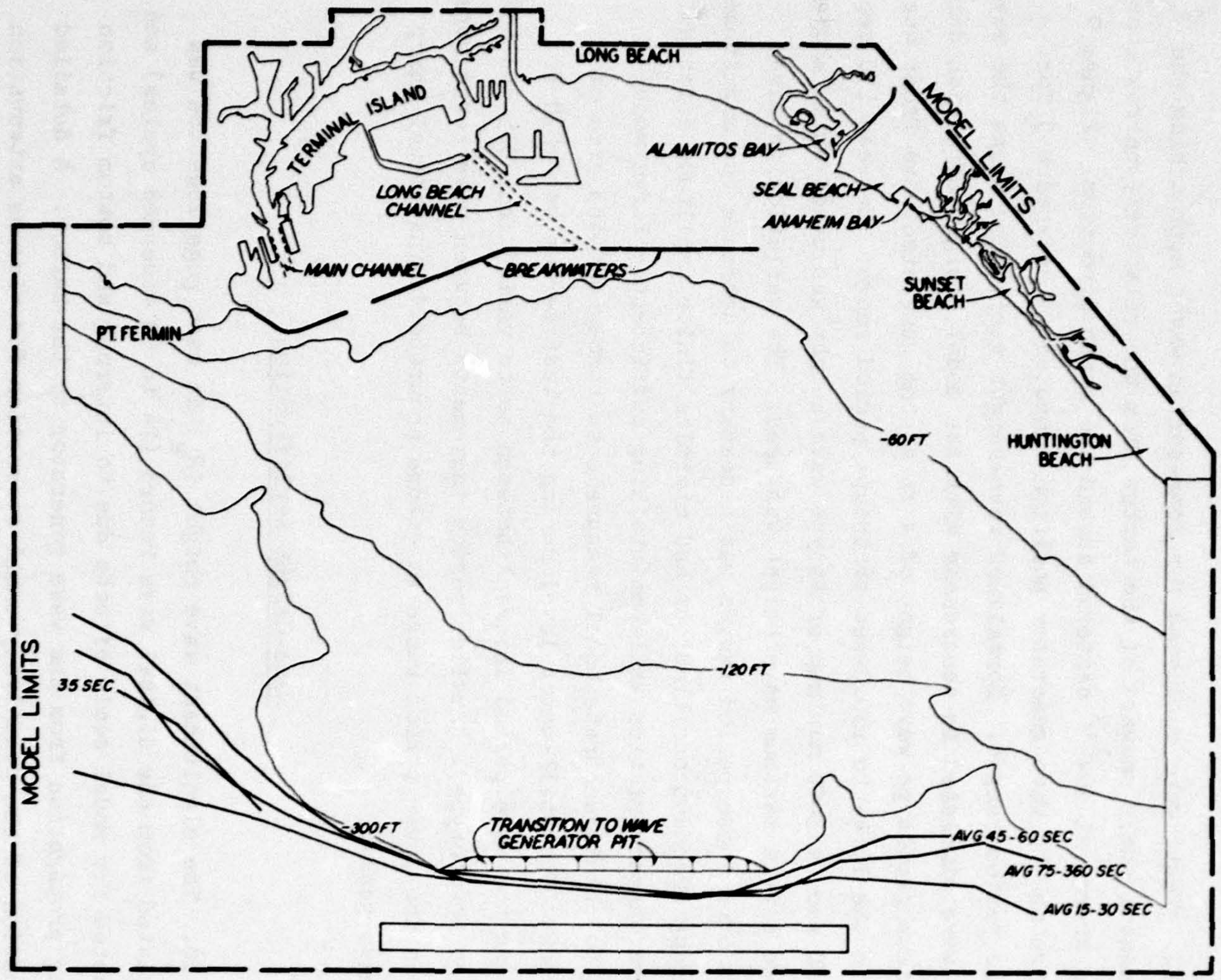

Figure 9. Mean wave generator positions

the incident wave height at the harbor mouth. This definition results from the fact that the standing wave height for a straight coast with no harbor would be twice the incident wave height due to superposition of the incident and reflected waves. In the hydraulic model, the wave heights also are affected by refraction and are variable along the outer harbor breakwater, are significantly different at Queen's Gate and Angel's Gate, and are even variable along the model wave generator. Consequently, another definition of amplification is necessary. A consistent definition can be based on the incident wave height in deep water seaward of the model wave generator location. Therefore wave-height amplification (R) for the model was calculated as the ratio of the significant wave height at each gage location to the incident wave height H_i which would have occurred at the initial wave-front position (approximately 38 miles seaward of the breakwater) used in the model design wave refraction analysis, or

$$R = \frac{H_s}{H_i} \tag{3}$$

The initial wave-front position for the refraction analysis is shown in Figure 5 for a 60-sec wave period. Average depth along the initial wave front is approximately 3470 ft. The model wave height H_m at each gage location was corrected for shoaling differences due to model distortion when calculating prototype wave heights or:

$$H_s = H_r \frac{K_s^{P,G}}{K_s^{M,G}} H_m \tag{4}$$

where

H_r = the vertical scale ratio

$K_s^{P,G}$ = the prototype shoaling coefficient

$K_s^{M,G}$ = the model shoaling coefficient at the gage locations

Similarly, the prototype generated wave height H_w^P is

$$H_w^P = K_r \frac{K_s^{P,W}}{K_s^{M,W}} H_w^M \tag{5}$$

where

K_r = the refraction coefficient

$K_s^{P,W}$ = the prototype shoaling coefficient evaluated at the wave generator position

$K_s^{M,W}$ = the model shoaling coefficient evaluated at the wave generator position

H_w^M = the model generated wave height

The prototype wave height at the wave generator may also be written in terms of H_i as

$$H_w^P = K_r \frac{K_s^{P,W}}{K_s^{P,A}} H_i \tag{6}$$

where $K_s^{P,A}$ is the shoaling coefficient at the initial refracted wave-front position for the 3470-ft average depth. Substituting from Equations 2, 3, and 4, the wave-height amplification may be written in terms of model wave heights as

$$R = K_r \frac{K_s^{P,G}\, K_s^{M,W}}{K_s^{P,A}\, H_w^M\, K_s} H_m \tag{7}$$

The refraction coefficient is available from the model design refraction analysis, and the shoaling coefficients are a function of wavelength and water depth.

PART IV: HARBOR OSCILLATION RESULTS

Test Results

20. Wave tests were conducted for existing conditions (base plan) and for the Modified Phase I plan. Wave gage locations in the existing harbor and the Modified Phase I plan are shown in Plates 1 and 2. Due to the placement of gages in and near areas of proposed harbor improvement, wave gages at the same locations in the existing harbor area usually will not have the same number for both plans. Table 1 lists the gage numbers and corresponding locations of gages used in the Base Plan and Modified Phase I plan including the 36 corresponding gages for both plans. Wave-height amplification data at each gage location for existing conditions are shown in Plates 3-51. Amplification data for the Modified Phase I plan gages listed in Table 1 also are plotted for comparison with existing conditions on the corresponding plates. On the plates which show comparison plots, the time scale changes at 120 sec in order to provide a readable comparison of the amplification data in the shorter period range. Wave-height amplification data for the remaining Modified Phase I plan gage locations in and near the proposed improvements are presented in Plates 52-64. Contour plots of the modes of oscillation for resonant periods are presented in Plates 65-91. The contour plots of wave-height amplification show the nodes and antinodes of the resonant oscillation. Maximum currents and the maximum horizontal water displacement will occur near the nodal area of the oscillation. Maximum vertical movement of the water will occur at the antinodes of the oscillation. Location of nodes, antinodes, and water particle motions for an idealized rectangular channel with a node at the channel entrance are shown in Figure 10.

Existing Harbor

East Channel

21. Model wave-height amplification data for gage 6, Plate 8,

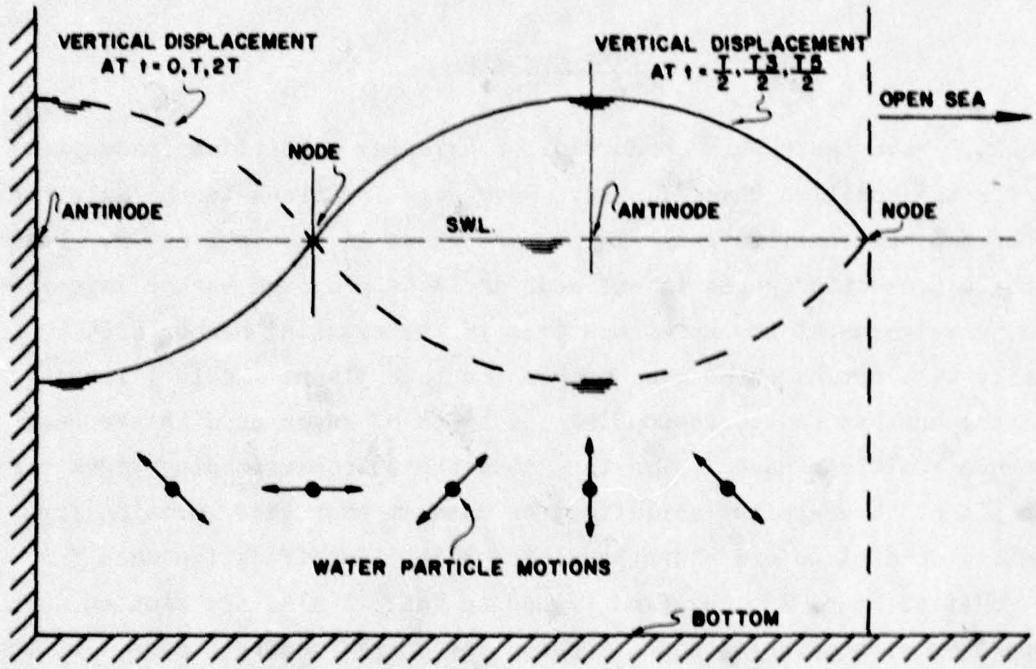

Figure 10. Node, antinode, and water particle motions in a rectangular channel open to the sea with a node at the channel entrance

indicated maximum amplification occurred for the fundamental mode of oscillation at 385 sec for existing conditions and at 370 sec for the improvement plan. The second largest amplification for existing conditions developed at 96 sec. A similar oscillation developed for the improvement plan at 95 sec but with amplification approximately 14 percent lower. The resonant peak with the third largest amplification was at 285 sec for existing conditions and 265 sec for the improvement plan. Maximum amplification for this mode increased approximately 10 percent for the improvement plan.

22. For existing conditions, the modes of oscillation of the 96-sec, 285-sec, and 385-sec oscillations in East Channel are shown in Plates 65-67. Corresponding modes of oscillation for the Modified Phase I plan are shown in Plates 76, 77, and 78. As shown in Plate 67, the fundamental mode of oscillation at 385 sec has a nodal area outside the channel near the tip of berth 50 at the Bulk Loading Facility. The

370-sec oscillation mode is similar, but with the nodal area closer to the channel entrance as expected for a shorter wave period and corresponding shorter wavelength. Higher currents associated with the nodal area occur near berth 50 for each of the oscillations. The 280-sec mode of oscillation also is a fundamental mode of oscillation but with the nodal area located just inside the channel entrance and with an antinode near berth 50. The development of two modes of oscillation, each of which appears to be a fundamental mode for East Channel, is probably due to the submerged bar along the east side of East Channel at a depth of 20 ft mllw relative to a dredged depth of approximately 50 ft mllw in the channel. This submerged bar has the effect of increasing the length of the channel along the east side opposite berth 50. At 96 sec, a nodal area is located at approximately one-third the length of the channel from the north end and at the channel entrance. The 96-sec oscillation, second harmonic of the 280-sec oscillation, has potential for a more severe impact on ship mooring conditions due to the higher currents in the nodal areas and the tendency of general cargo ships to respond over a period range including 96 sec. The 95-sec oscillation, for the improvement plan shown in Plate 76, was similar but with lower amplification.

23. Estimates[4] of spectral energy density from the WES prototype wave gage data from the same location as model gage 6 for 10 time periods during which concurrences of medium/heavy ship motion were reported in East Channel indicated that the maximum wave energy occurred in the channel near 387.5 sec with a smaller peak near 267.5 sec. These two resonant periods correlate well with the fundamental modes found in the model study (385 sec and 285 sec). The 96-sec oscillation is apparent in the prototype data but is not as well defined. The estimates of spectral energy density are dependent on the distribution of incident wave energy over the frequency range and the relative magnitudes of peaks in the energy spectrum will be affected by the incident energy level. Analysis of the prototype data is discussed extensively in Reference 4 and results of the analysis are given. Typical spectral energy density results from the analysis in Reference 4 for the north end

of East Channel are shown in Figure 11. The results present the maximum, minimum, and average spectra for 14 overlapping time periods starting on 16 October 1971.

West Channel

24. Wave-height amplification data for existing conditions at the rear of West Channel, shown in Plate 7, indicated a maximum amplification of 4.0 at 209 sec with two small resonant peaks at 67 sec and 91 sec, with amplification values of 1.3 and 1.1, respectively. Maximum amplification for the proposed plan was approximately 33 percent lower and at a period of 218 sec. Resonant oscillations again occurred near 67 sec and 91 sec with amplification similar to that for existing conditions. For each plan, amplification was increasing at the 410-sec limit of the period range tested.

Los Angeles Main
Channel and Inner Harbor

25. Wave-height amplification for existing conditions in the Los Angeles Main Channel and Inner Harbor was low in the period range included in the study, except at the Main Channel entrance and near the upper limit of the period range. Amplification data for gage 11, located in the center of the channel entrance, indicated resonant peaks of 1.7, 1.6, 1.4, and 1.8 at 108, 167, 218, and 270 sec, respectively. Resonant peaks at the four periods were evident in the amplification data for the Inner Harbor, particularly at gages 16 and 17, but with a lower peak amplification. In general, the Los Angeles Inner Harbor area had relatively low amplification of the incident wave energy except as indicated near the upper limit of the test series. The lack of development of any strong resonant peaks in the Inner Harbor, such as occurred in East Channel, does not mean that long-period wave energy did not penetrate into the Inner Harbor, but that the Inner Harbor did not respond to the long-period wave energy over the period range tested.

26. Maximum amplification in the Inner Harbor for the improvement plan was relatively low and similar to that for existing conditions except near the upper limit of the period range tested. The resonant oscillation indicated for existing conditions near 410 sec peaked for

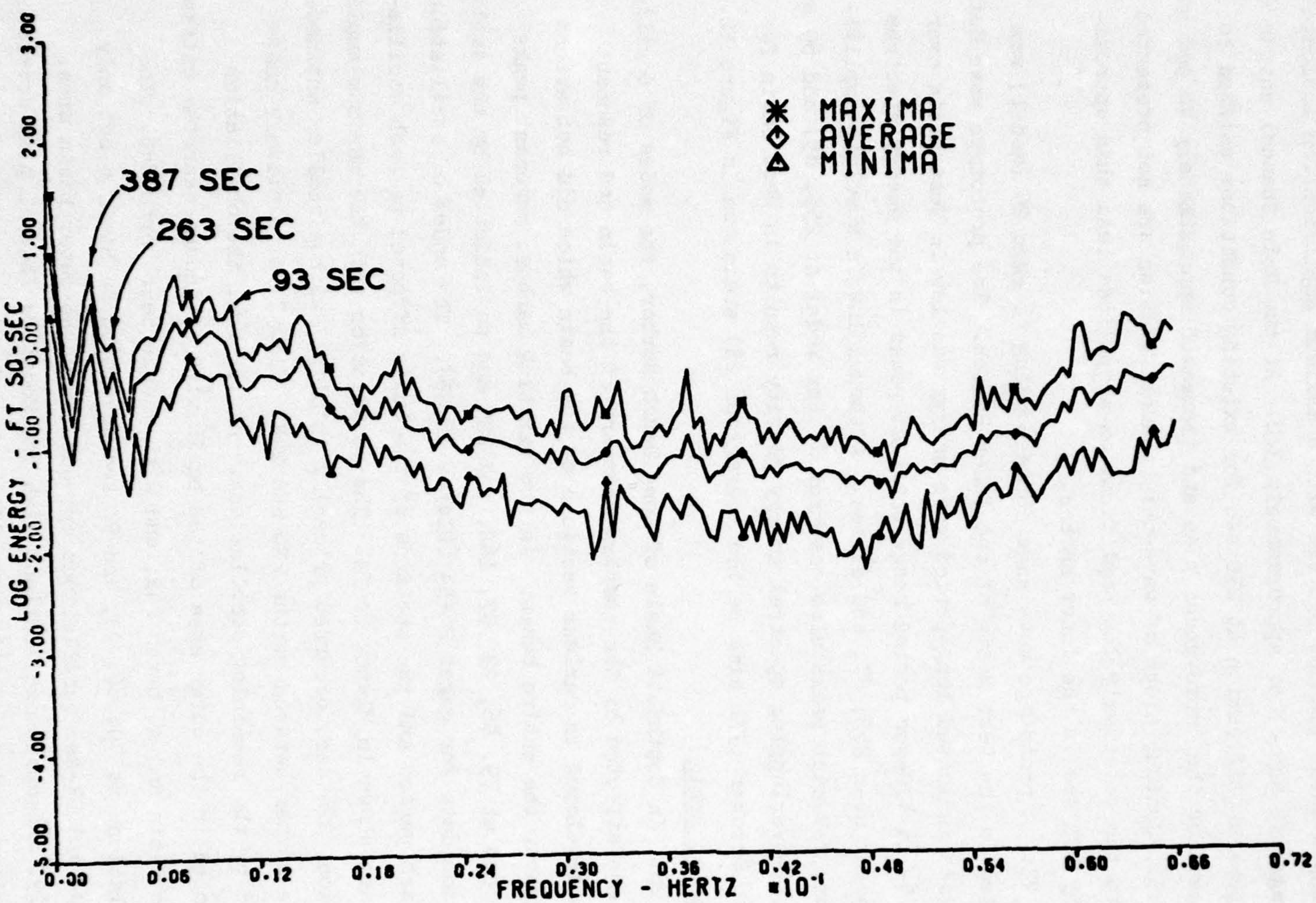

Figure 11. Typical spectral energy density results for the East Channel

the improvement plan at 390 sec with a maximum amplification indicated by gages 16 and 17 of approximately 3.0. At the Main Channel entrance, the peak amplification at 270 sec for existing conditions shifted to 265 sec for the improvement plan and increased approximately 40 percent to 2.5. Contour plots of wave-height amplification are not presented due to the relatively low amplification at periods less than approximately 400 sec in the Inner Harbor.

27. A prototype wave gage corresponding to gage 20 (model) was located in the West Basin of the Inner Harbor. The prototype wave data analysis indicated long-period wave energy was low in West Basin over the 15- to 410-sec period range but that peaks in the energy spectrum did occur near 263, 87, and 61 sec. Although low in absolute amplification, resonant peaks also occurred in the model at 255, 85, and 60 sec. Typical overlapping spectral energy density results in West Basin for the 16 October 1971 time period (paragraph 23) are shown in Figure 12.

Southeast Basin

28. In Southeast Basin of Long Beach Harbor, the modes of oscillation are affected by the complex geometry of the basin and resonant modes developed in various sections of the basin which did not extend throughout the entire basin. In the existing harbor, resonant peaks developed at 79, 86, 93, 97, 162, and 226 sec as indicated by the amplification data for gages 26-34 (Plates 28-36). The modes of oscillation for each period and the sections of the basin affected by each oscillation are shown in Plates 68-73. The oscillation with the maximum amplification, 226 sec, occurred primarily in Slip 7 with a smaller antinode in the corner between berths 236 and 242. Slip 7 is relatively unaffected by the remaining oscillations. At 162 sec, the oscillation developed in the outer area of the basin with antinodes near the entrance to the basin and at berth 242, and with a node near berth 246. The oscillations at 79, 86, 93, and 97 sec developed in Basin 6 but only the 79- and 97-sec oscillations extended into the outer basin area.

29. Resonant oscillations with the Modified Phase I plan developed at similar periods of 243, 153, 88, and 78 sec (also shown in Plates 28-36). The amplification for oscillations at 57 and 63 sec, relatively

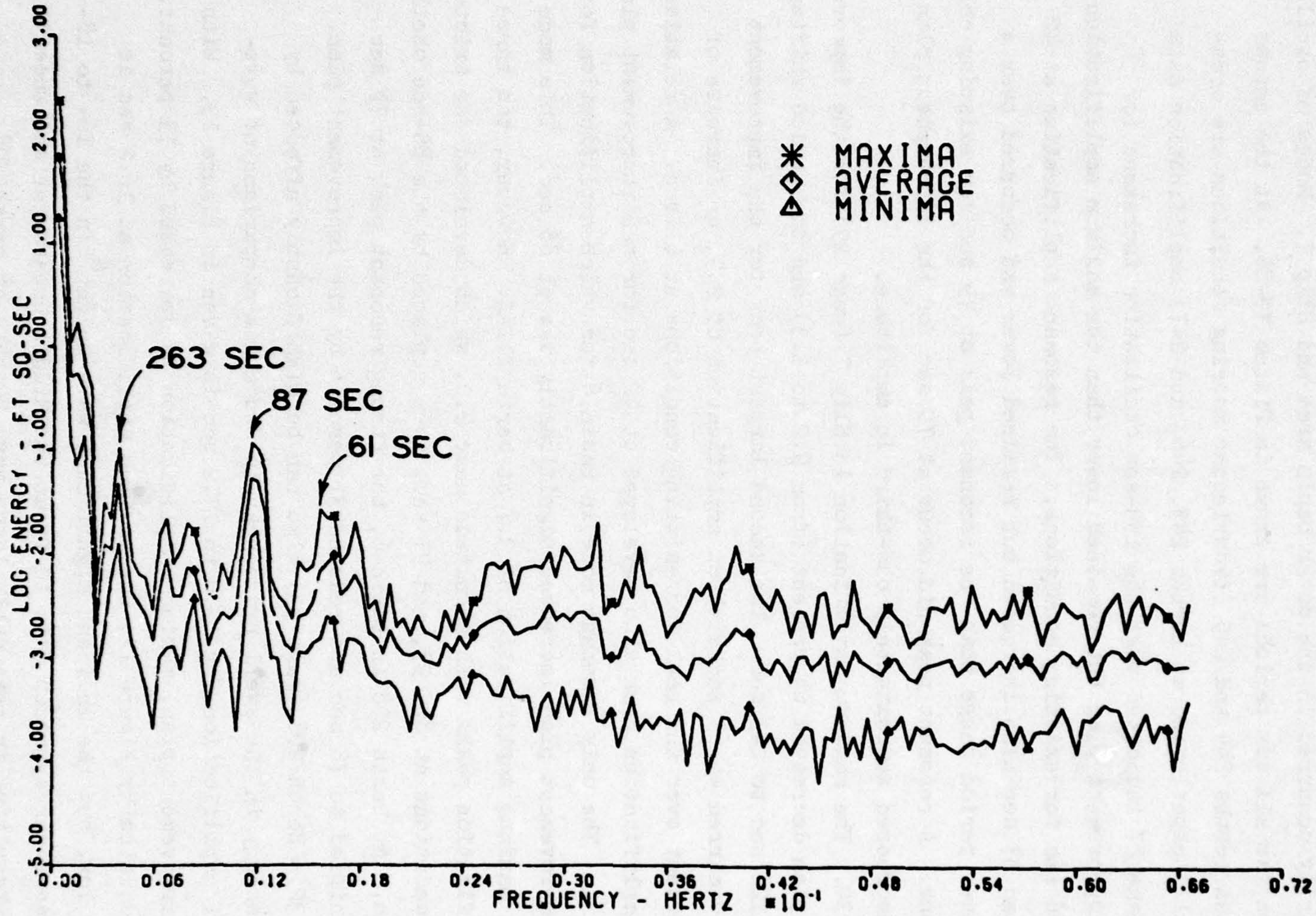

Figure 12. Typical spectral energy density results for West Basin

low for existing conditions, increased substantially to 2.4 and 2.9 and primarily occurred in the outer basin area and Slip 7. Modes of oscillation for all six periods are shown in Plates 79-84. At the corner between berths 244 and 245 (troublesome mooring conditions are occasionally experienced at berths 245, 246, and 247) amplification data for gage 27 indicated that the 153-sec oscillation increased for the improvement plan but remained lower than the maximum amplification at 226 sec for existing conditions. The resonant amplification at 42 sec and 57 sec also increased but remained lower and occurred over a narrower period range than the resonant peak at 79 sec for existing conditions. A resonant peak did occur at 79 sec for the improvement plan but decreased approximately one-third in amplitude.

30. The maximum amplification in Slip 7 (gage 29) for the improvement plan decreased 64 percent (from 9.2 to 3.3) and the period shifted from 226 sec to 243 sec. The second largest peak for the improvement plan occurred at 63 sec with an amplification of 2.9, an increase of 21 percent over the peak for existing conditions at 61 sec. A relatively low amplification peak also developed at 42 sec for the improvement plan.

31. The only resonant mode in Basin 6 for which amplification for the improvement plan increased significantly was at 88 sec. This mode had a maximum amplification of 3.7 at berth 211-A. However, the three amplification peaks with magnitude near 2.0, which developed for existing conditions at 86, 93, and 97 sec, were replaced by the 88-sec oscillation. At berth 208 in Basin 6, the strong resonant peak at 79 sec was shifted to 78 sec and reduced 31 percent by the improvement plan.

32. Berth 208 (gage 33) also can be significantly affected by wave energy in the swell range near 16 sec and a comparison of wave-height amplification for 15.6 to 17.2 sec is given in Figure 13. With the improvement plan, maximum amplification is decreased by 13 percent. As indicated by Figure 13, the maximum amplification at 16.2 sec is quite low, but the incident significant wave height[6] in the 16- to 18-sec range can approach 8 to 10 ft at the Middle breakwater and Queen's Gate, resulting in reasonably large wave heights at berth 208.

33. In the WES prototype data acquisition program, prototype gages

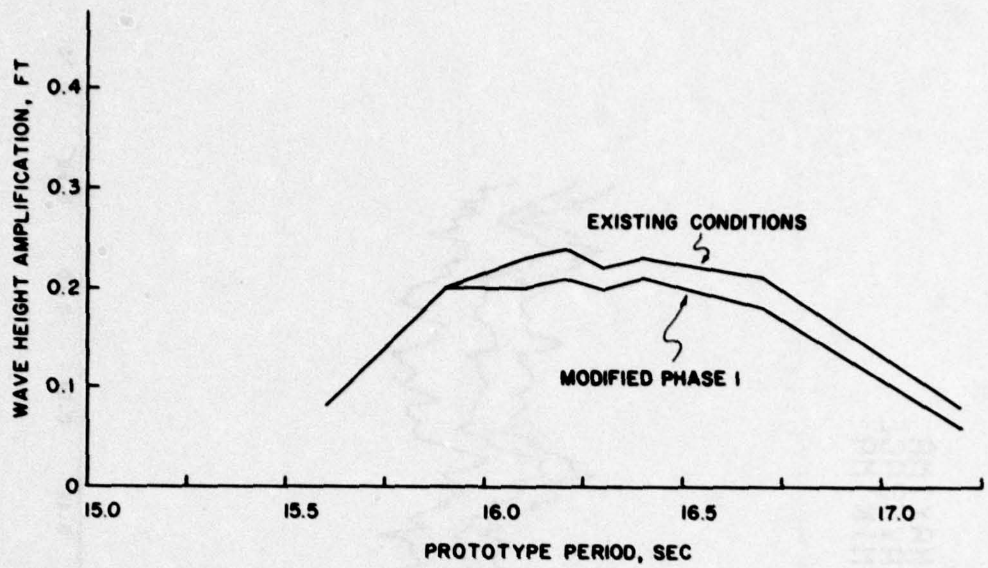

Figure 13. Comparison of wave-height amplification for existing conditions and the Modified Phase I plan at berth 208 in the swell range

were at identical locations as model gages 29 and 33. The distinct resonant peaks at 61 and 226 sec in the model wave-height amplification data for Slip 7 (gage 29) correspond closely with estimates of increased spectral energy density from the prototype near 62 and 217.5 sec. At berth 208 (gage 33), the resonant peaks at 79 and 86 sec correspond closely with estimates of spectral energy density from the prototype wave data near 81 and 87 sec. Typical overlapping spectral energy density results for the 16 October 1971 time period (paragraph 23) are shown in Figures 14 and 15 for Slip 7 and Basin 6, respectively. The peak at 93 sec for Slip 7 results from an increased incident wave energy level at 93 sec in comparison with the energy near 63 sec.

East Basin and Back Channel

34. Maximum amplification observed during the study for existing conditions occurred in Slip 3 of East Basin in the Port of Long Beach (gage 42). The response for gage 42, shown in Plate 44, is generally low except near 224 sec where a maximum amplification peak of 10.2 occurred. The mode of oscillation is shown in Plate 74 and is the fundamental mode with a nodal area just outside the slip entrance. The lack

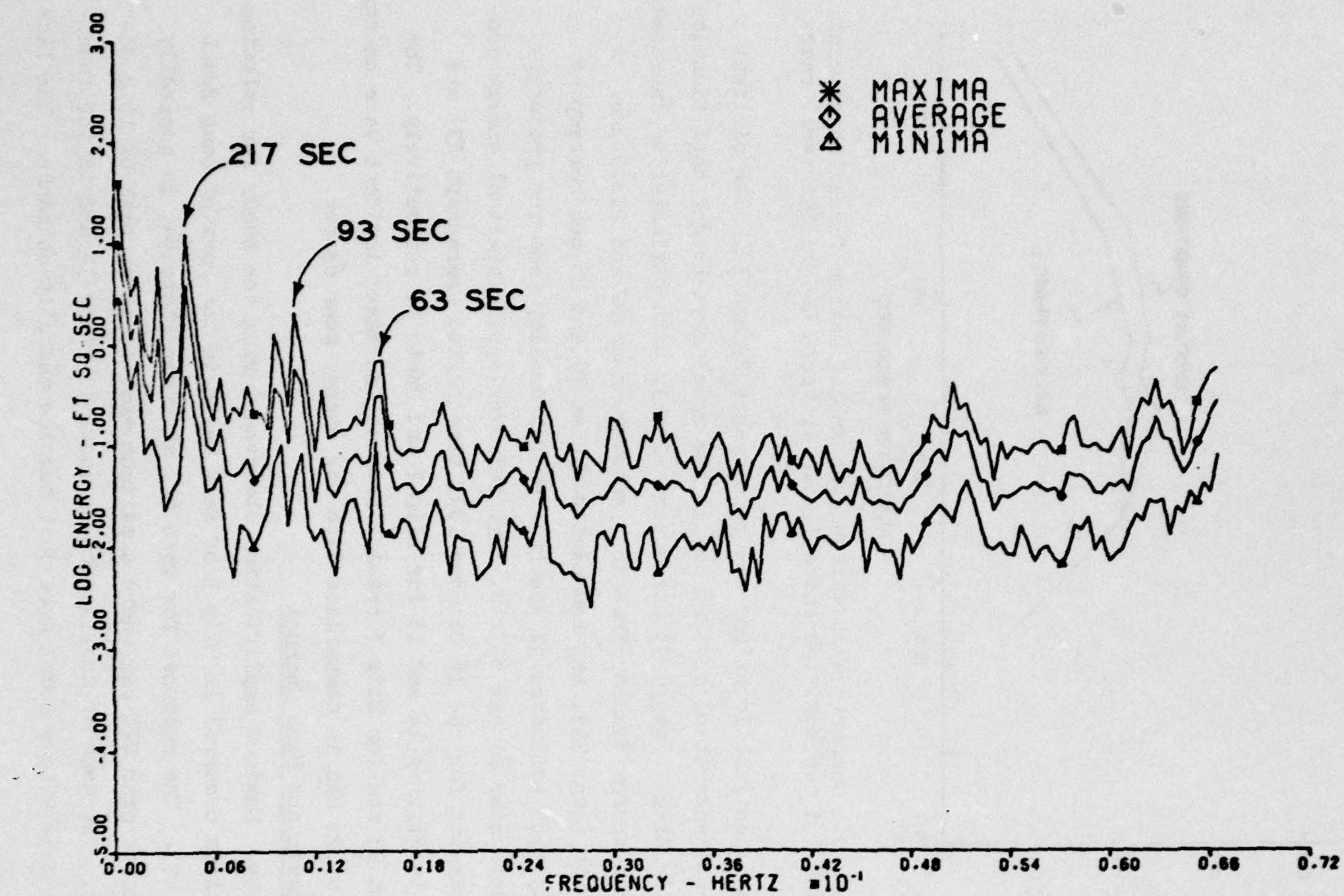

Figure 14. Typical spectral energy density results for Slip 7

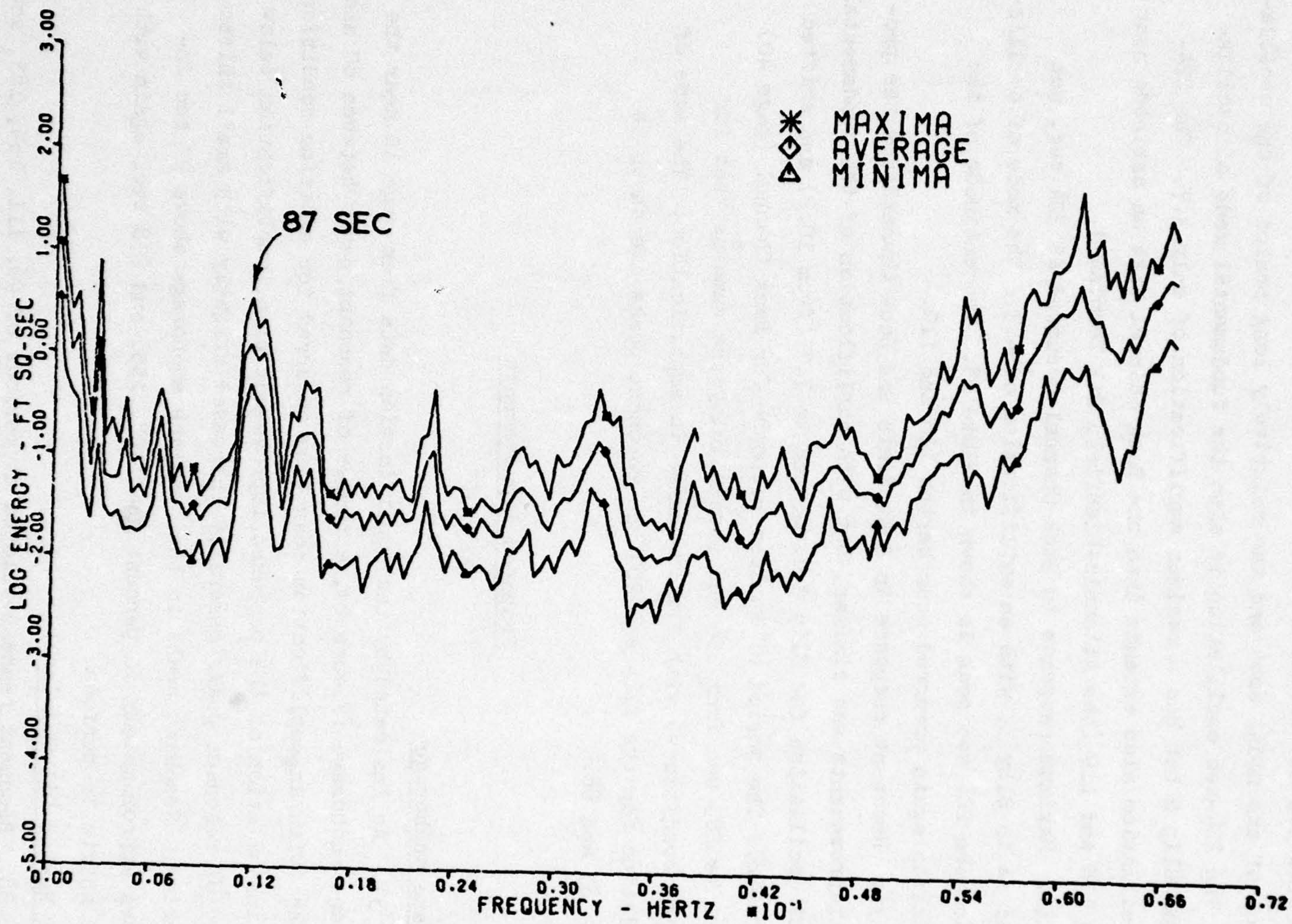

Figure 15. Typical spectral energy density results for Basin 6

of reported troublesome mooring conditions in the slip indicates that the oscillation has little effect on ship mooring, probably due to the location of the nodal area and the relatively long period of the oscillation. The 224-sec oscillation is also the fundamental mode of oscillation for Slip 2 but has a maximum amplification of only 3.7. The 224-sec oscillation also extends into the Back Channel with an antinode near berths 118 and 119 (the Atlantic-Richfield Oil Terminal).

35. Maximum response in Back Channel occurred at 204 sec, not 224 sec as in Slip 3, with an amplification of 4.3. The mode of oscillation for the 204 sec peak is shown in Plate 75. The antinode of the oscillation again occurred near berths 118 and 119.

36. Resonant response in East Basin and Back Channel for the proposed improvements was similar, but with amplification of the fundamental mode of oscillation for Slip 3 decreased to 7.7 (from 10.2) and shifted to 218 sec. The period of maximum response for Back Channel (gage 40) shifted to 203 sec from 204 sec (essentially the same as that for existing conditions) with little change in amplification. The mode of oscillation for the 218- and 203-sec resonant peaks are shown in Plates 85 and 86.

Proposed Improvements

Seaplane anchorage

37. As indicated by the amplification data from gage 15 near the seaplane anchorage (Figure 2), a number of resonant peaks between 60 and 300 sec (with an amplification near 4.0) occurred for existing conditions. With installation of the proposed improvement plan, amplification below 90 sec of resonant peaks generally increased slightly with small shifts in period. Resonant peaks in the seaplane anchorage above 90 sec increased approximately 50 percent near 108, 155, and 278 sec, again with small shifts in periods.

Outer Harbor Oil Terminal

38. Resonant peaks developed at periods of 96, 111, 169, 183, and 295 sec (Plates 57-63) in the oil terminal. Modes of oscillation for

the resonant periods are shown in Plates 87-91. The 295-sec oscillation is present on all gages in the oil terminal and had an antinode in the center of the terminal with nodes well outside the terminal. The 169- and 183-sec oscillations were similar and had antinodes near the center of the oil terminal but with nodal areas closer to the east and west ends of the terminal than the 295-sec oscillation. The 169- and 183-sec oscillations also did not extend over as broad a period range as the 295-sec oscillation and were approximately 40 percent lower in maximum response.

39. The 111-sec oscillation developed primarily on the north side of the center dike and had relatively low amplification in the area of the dredged channel and the oil terminal berths. As shown in Plate 88, the oscillation north of the center dike appears to be a fundamental mode between the dike and the south face of Pier J, but a fundamental mode of this type would have a period near 60 sec, not 111 sec. Analysis of the amplification data for the oscillation indicated that a dual mode of oscillation had developed with the antinodes near each end of the center dike 180 deg out of phase. The corresponding antinodes along Pier J were also 180 deg out of phase. For the cross-channel oscillation, the antinodes of the oscillation adjacent to the center dike occurred with a phase lag of approximately 20 deg from the corresponding antinode adjacent to Pier J. The water particle displacement in the nodal area of the oscillation will tend to occur in a loop pattern rather than in the back-and-forth motion indicated in Figure 10.

40. At 96 sec, an oscillation developed with a node near the two eastern oil terminal berths. This mode of oscillation, shown in Plate 87, has the potential of creating troublesome ship motion in the surge component if a resonant frequency of the ship and mooring system is near 96 sec.

Summary

41. Periods and amplitudes of maximum resonant response for various berthing areas in Los Angeles and Long Beach Harbors were:

	Plan			
	Existing Conditions		Modified Phase I	
Location	Period sec	Amplification	Period sec	Amplification
Los Angeles Harbor				
West Channel	209	4.0	218	3.7
East Channel	96	4.1	95	3.5
	280	3.7	265	4.1
	385	11.0	370	12.0
Long Beach Harbor				
Southeast Basin	79	4.9	57	2.7
	86	2.2	63	2.9
	93	1.8	78	3.5
	97	2.1	88	3.7
	162	2.9	153	4.2
	226	9.2	243	3.3
East Basin	224	10.2	218	7.7
Back Channel	204	4.3	203	4.1
Outer Harbor Oil Terminal	Not Applicable		96	4.0
			111	4.1
			169	4.3
			183	4.0
			295	7.1

As indicated by the preceding tabulation, resonant oscillations generally developed at similar periods for existing conditions and the Modified Phase I plan. Several exceptions occur in Southeast Basin.

42. In the Outer Harbor Oil Terminal, nodal areas for the 169-, 183-, and 295-sec resonant peaks occurred outside the limits of the berthing area while the 96- and 111-sec resonant peaks possessed nodal areas near berthing areas.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

43. Wave-height amplification in the Los Angeles and Long Beach Harbors was not substantially altered by the Modified Phase I plan. Major resonant peaks in existing berthing areas which increased significantly (greater than 20 percent in magnitude) were in the shorter period range (less than 100 sec with the exception of the 153-sec peak in Southeast Basin) and occurred over a narrow period band. Only a small amount of energy in the incoming wave spectrum would be contained over the narrow period range of these sharp, narrow peaks; consequently, they should have a relatively small effect on ship response. In the longer period range above 200 sec, the broad resonant peaks in East Channel, Southeast Basin, and East Basin have increased slightly in amplification or have decreased. Specific conclusions resulting from the comparison of wave data for existing conditions and for the Modified Phase I plan are:

- a. Resonant periods in the model and prototype are in agreement for existing conditions.
- b. Wave-height amplification in existing berthing areas has generally not changed significantly or has decreased.
- c. In East Channel, wave-height amplification is similar for the Modified Phase I plan below 200 sec with a 15 percent decrease in maximum amplification near 96 sec.
- d. In Southeast Basin, resonant amplification at several periods increased but remained lower than the resonant amplification for existing conditions at nearby periods.
- e. Ship mooring conditions should not be adversely affected in the existing harbor by the Modified Phase I plan with the possible exception of (1) Southeast Basin where the response of moored ships to shorter periods (40- to 60-sec range) could increase and (2) East Channel where the resonant response of the channel at the two longer period modes of oscillation increased by 10 percent.
- f. Of the six resonant modes of oscillation which developed in the proposed Long Beach Outer Harbor Oil Terminal, only one mode (96 sec) had a node located near an oil terminal berth. Amplification at 96 sec is relatively low and mooring conditions may be satisfactory provided the moored ship does not respond significantly to a period near 96 sec.

44. Wave-height amplification and resonant modes of oscillation for existing conditions and the Modified Phase I plan have been determined in the hydraulic model study. Moored ship response is a function of incident wave amplitude, frequency of incident wave spectrum, response of the harbor to wave excitation, types of mooring lines and configurations used, and characteristics of the ship period. Results from the model study may be used in a comprehensive numerical or experimental investigation of moored ship response to quantify the extent of potential moored ship motion for all 6 deg of freedom for either existing conditions or proposed improvement plans within the Los Angeles and Long Beach Harbors complex.

Recommendations

45. It is strongly recommended that either a numerical or experimental moored ship response study be undertaken to adequately quantify moored ship response in Los Angeles and Long Beach Harbors. The effect of increased wave-height amplification or a shift in the period of maximum amplification cannot be readily evaluated until the response function of the ship is known. Without ship response data, the effect of changes in resonant oscillations in the harbor must be inferred from comparison with existing conditions and from comparison between various berthing areas in the harbor for existing conditions.

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2. Pickett, E. B., Durham, D. L., and McAnally, W. H., Jr., "Los Angeles and Long Beach Harbors Model Study; Prototype Data Acquisition and Observations," Technical Report H-75-4, Report 1, Jun 1975, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

3. Crosby, L. G. and Durham, D. L., "Los Angeles and Long Beach Harbors Model Study; Observations of Ship Mooring and Movement," Technical Report H-75-4, Report 2, Jan 1975, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

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6. Hales, L. Z., "Transmission of Wave Energy Through and Overtopping of the Long Beach, California, Breakwater; Hydraulic Model Investigation," Miscellaneous Paper H-76-10, May 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Table 1

Corresponding Wave Gage Numbers and

Locations for Base Plan and the Modified Phase I Plan

Base Plan	Modified Phase I Plan	Location
1	1	Angel's Gate - Center
2	2	Outside Angel's Gate - West
3	3	Inside Angel's Gate - West
4	4	Bulk Terminal - Berth 47
5	5	West Channel - North End
6	6	East Channel - North End
7	7	East Channel - Midpoint
8	8	East Channel - Entrance
9	9	East Channel - Berth 51
10	--	East Channel - Berth 50
11	10	Main Channel - Entrance
12	11	Main Channel - South of Reservation Point
13	--	4000 ft South of the Seaplane Basin Entrance
14	--	SW Corner Reeves Field - Waterside
15	17	NE Corner Seaplane Basin
16	19	Main Channel (East Side) Berth 229
17	18	Main Channel (West Side) Berth 89
18	--	Inner Harbor - Berth 109
19	--	Turning Basin - Berth 151
20	20	West Basin - North End
21	21	East Basin - East Side
22	22	Queens Gate - Center
23	23	Outside Queen's Gate - West
24	24	Inside Queen's Gate - West

(Continued)

Note: Gages 18 and 19 for the Modified Plan are reversed from the order shown in the Draft Report. This is based on locations shown in Plates 1 and 2.

(Sheet 1 of 3)

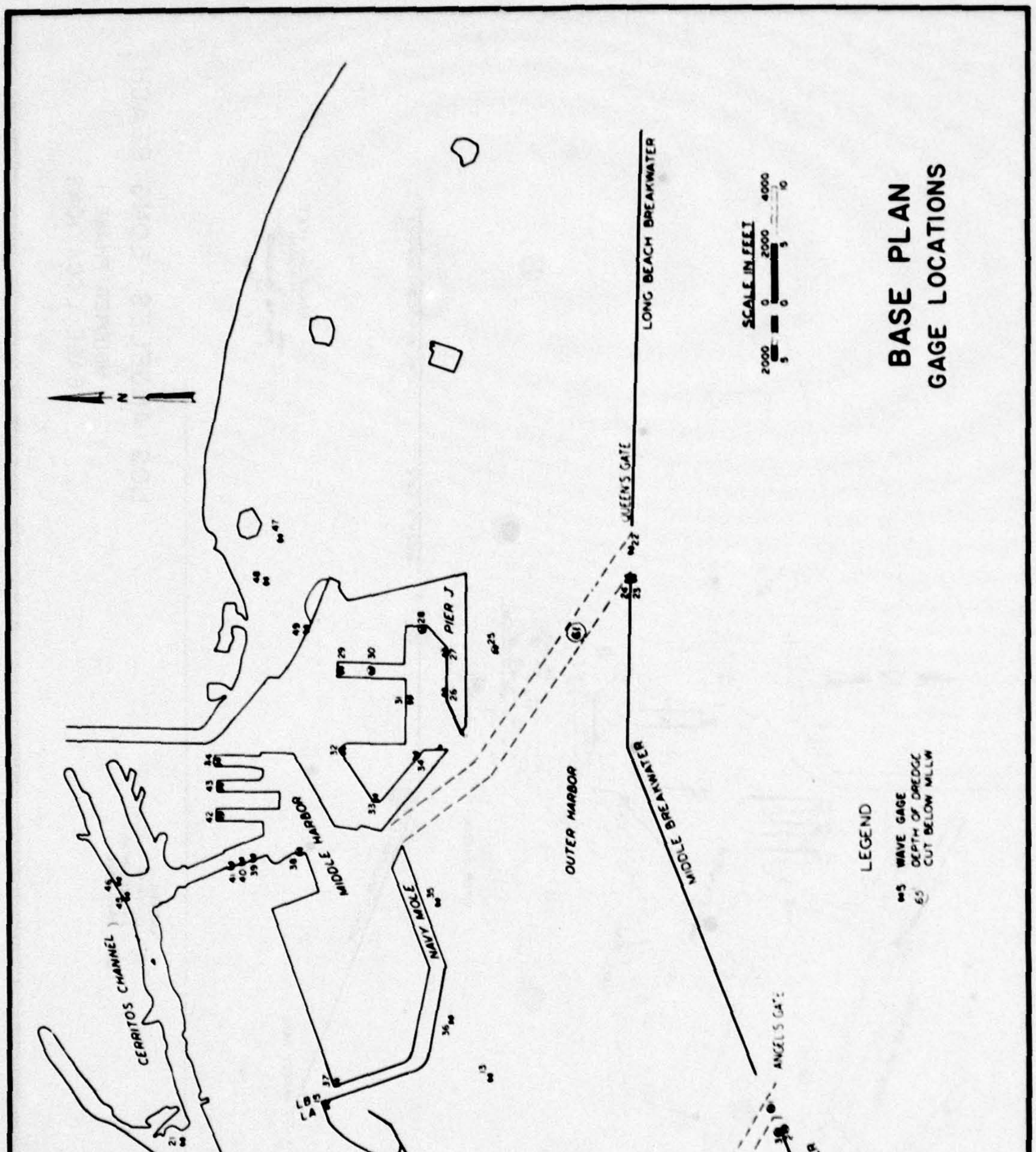
Table 1 (Continued)

Base Plan	Modified Phase I Plan	Location
25	--	1000 ft South of Pier J - Center
26	32	Pier J - Berth 247
27	33	Pier J - Berth 245
28	34	Pier J - Berth 242
29	35	Slip 7 - North End (Berth 231)
30	36	Slip 7 - Midpoint
31	37	Pier G - South End
32	39	Basin 6 - Berth 211A
33	38	Basin 6 - Berth 208
34	40	Pier F - Berth 204
35	--	Navy Mole - South Center
36	--	Navy Mole - SW Diagonal
37	41	Navy - West Basin - NW Corner
38	--	Pier E - Berth 122
39	--	Pier E - Berth 120
40	45	Pier E - Berth 119
41	--	Pier E - Berth 118
42	42	Slip 3 - North End (Berth 27)
43	43	Slip 2 - North End (Berth 19)
44	44	Slip 1 - North End (Berth 11)
45	46	Berth 87 - Texaco Terminal
46	--	Berth 85 - Texaco Terminal
47	47	Island Grissom - South Side
48	--	2000 ft West of Island Grissom
49	49	Queensway Bay - North/Q.M.
--	12	200-Acre Fill - South Face - West
--	13	200-Acre Fill - South Face - Center
--	14	200-Acre Fill - South Face - East

(Continued)

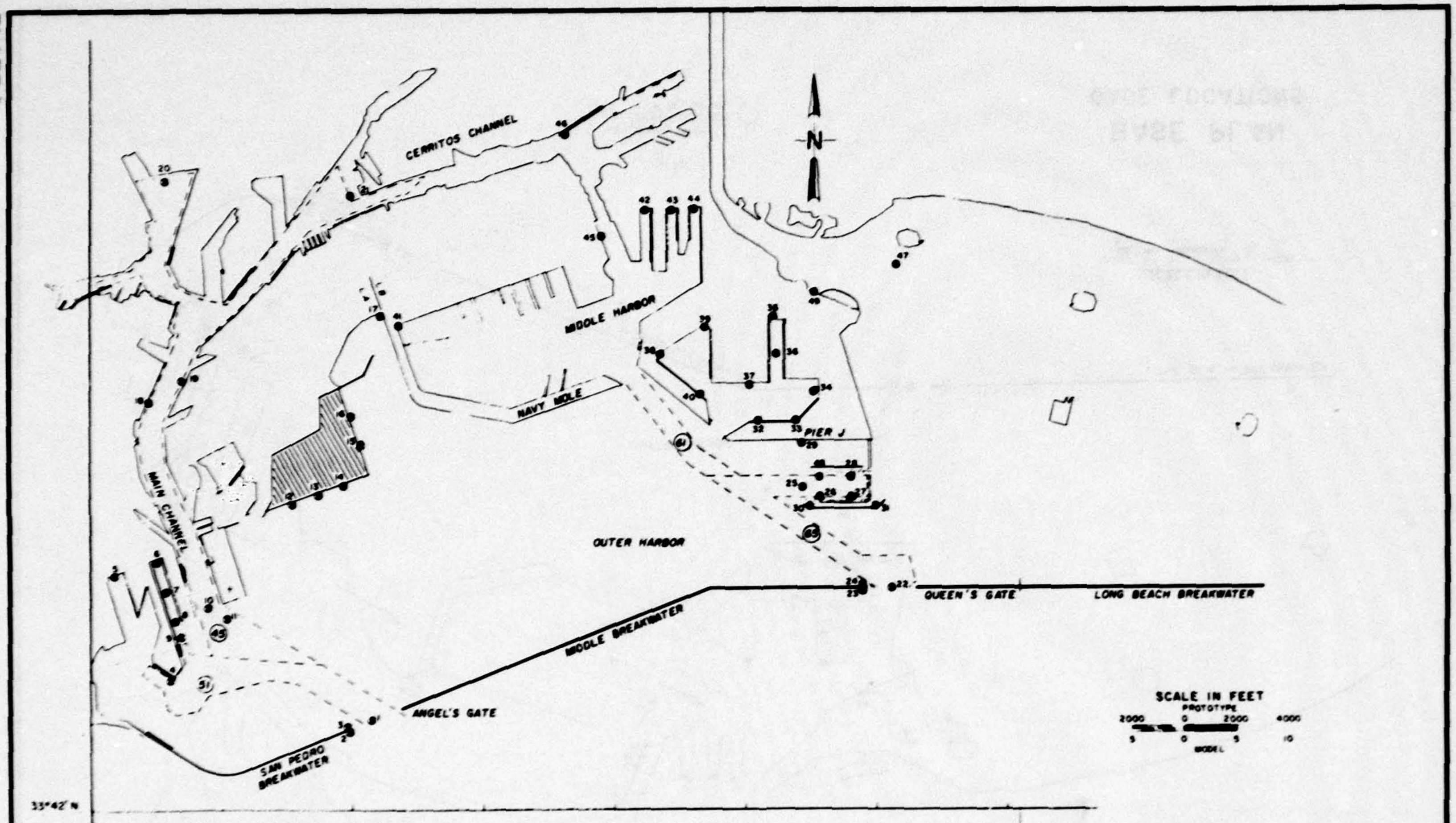
Table 1 (Concluded)

Base Plan	Modified Phase 1 Plan	Location
--	15	200-Acre Fill - East Face - South
--	16	200-Acre Fill - East Face - North
--	25	Long Beach Oil Terminal Basin - West Entrance
--	26	Long Beach Oil Terminal Basin - Berth 266
--	27	Long Beach Oil Terminal Basin - Berth 265
--	28	Long Beach Oil Terminal Basin - Berth 264
--	29	Pier J South Face - Center
--	30	Long Beach Oil Terminal B.W. - Inside - SW Corner
--	31	Long Beach Oil Terminal B.W. - Inside - SE Corner
--	48	Long Beach Oil Terminal Basin - Berth 263



BASE PLAN
GAGE LOCATIONS
SCALE IN FEET
2000 0 2000 4000
LEGEND
WAVE GAGE
DEPTH OF DREDGE CUT BELOW MLLW
LONG BEACH BREAKWATER
MIDDLE BREAKWATER
SAN PEDRO BREAKWATER
QUEEN'S GATE
ANGEL'S GATE
OUTER HARBOR
MIDDLE HARBOR
NAVY MOLE
PIER J
CERRITOS CHANNEL
MAIN CHANNEL
N

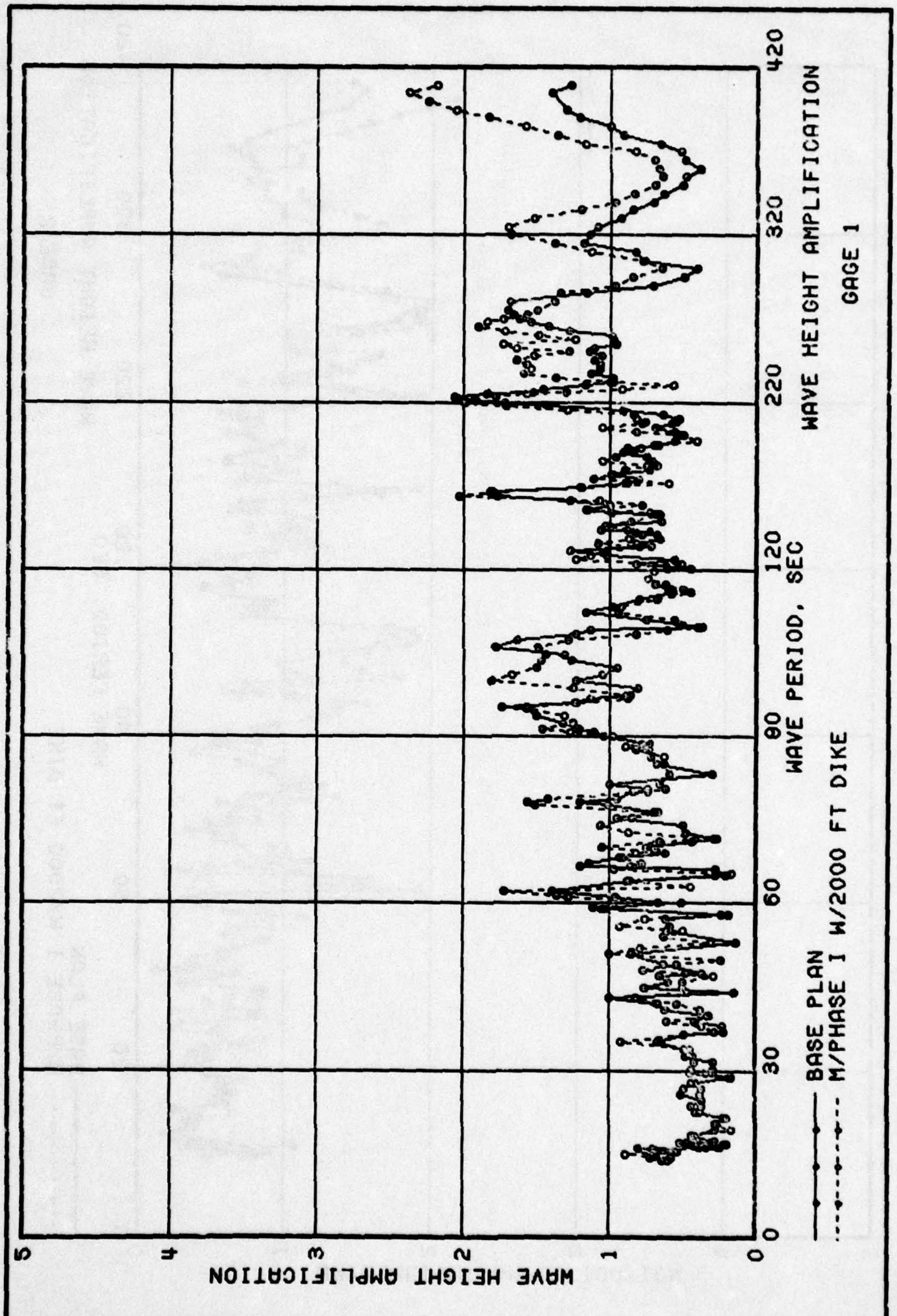
PLATE 1



LOS ANGELES-LONG BEACH

MODIFIED PHASE I
GAGE LOCATIONS

PLATE 2


WAVE HEIGHT AMPLIFICATION
GAGE 1
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
BASE PLAN
M/PHASE I W/2000 FT DIKE
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90
120
220
320
420
0
1
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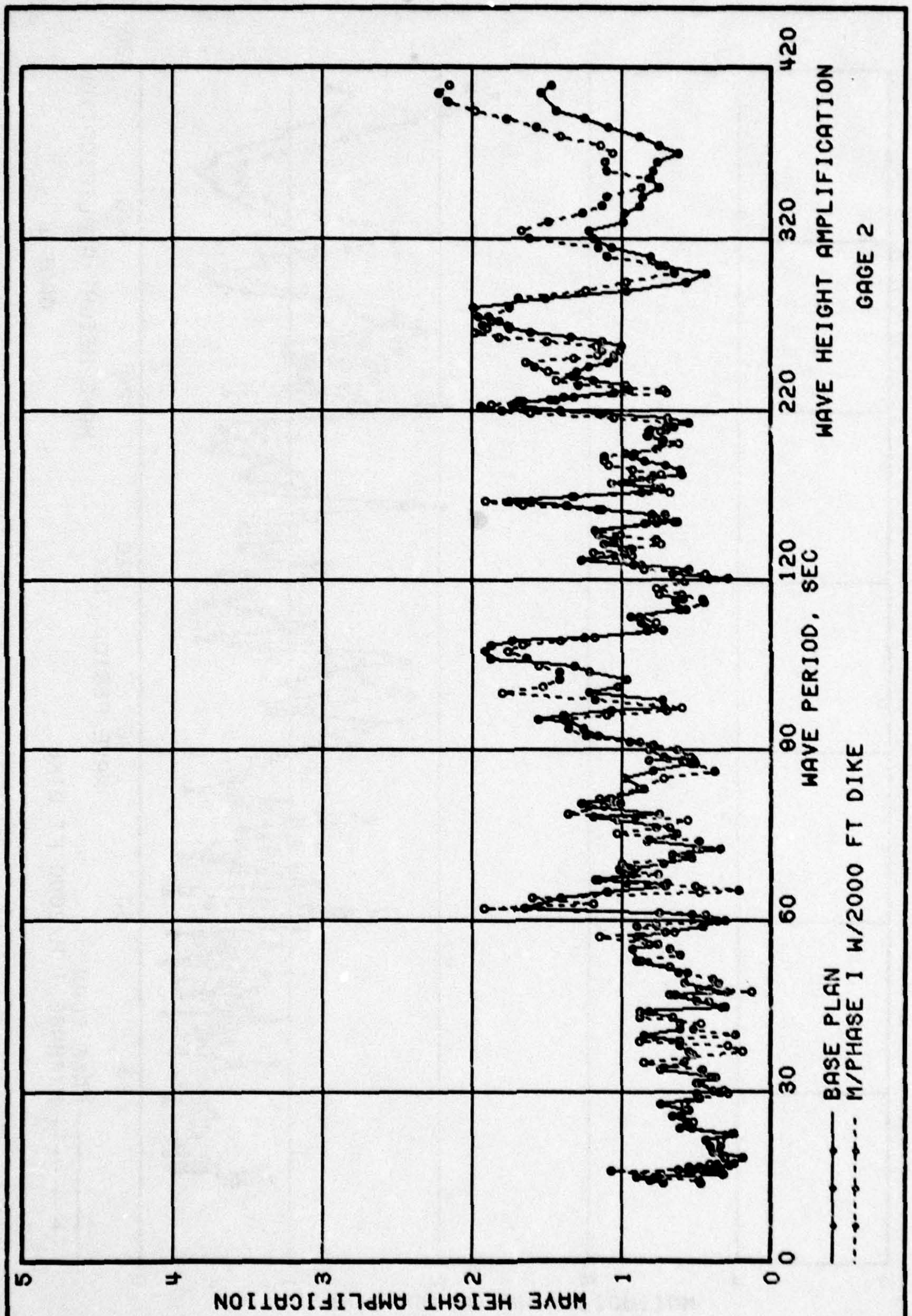
5

PLATE 3


WAVE HEIGHT AMPLIFICATION
GAGE 2
WAVE HEIGHT AMPLIFICATION
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2
3
4
5
WAVE PERIOD, SEC
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90
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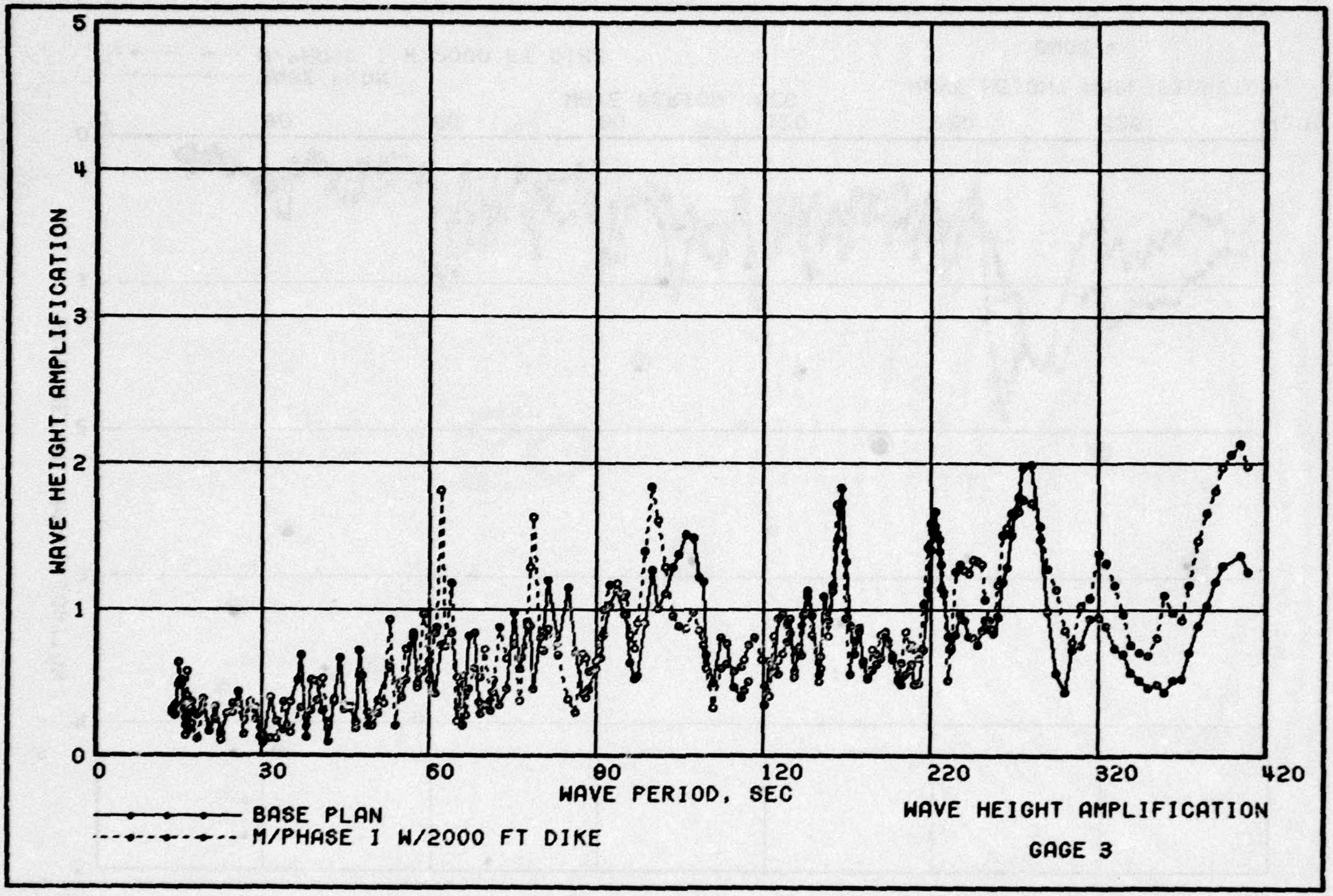
420
BASE PLAN
W/PHASE I W/2000 FT DIKE

PLATE 4


WAVE HEIGHT AMPLIFICATION
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1
2
3
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30
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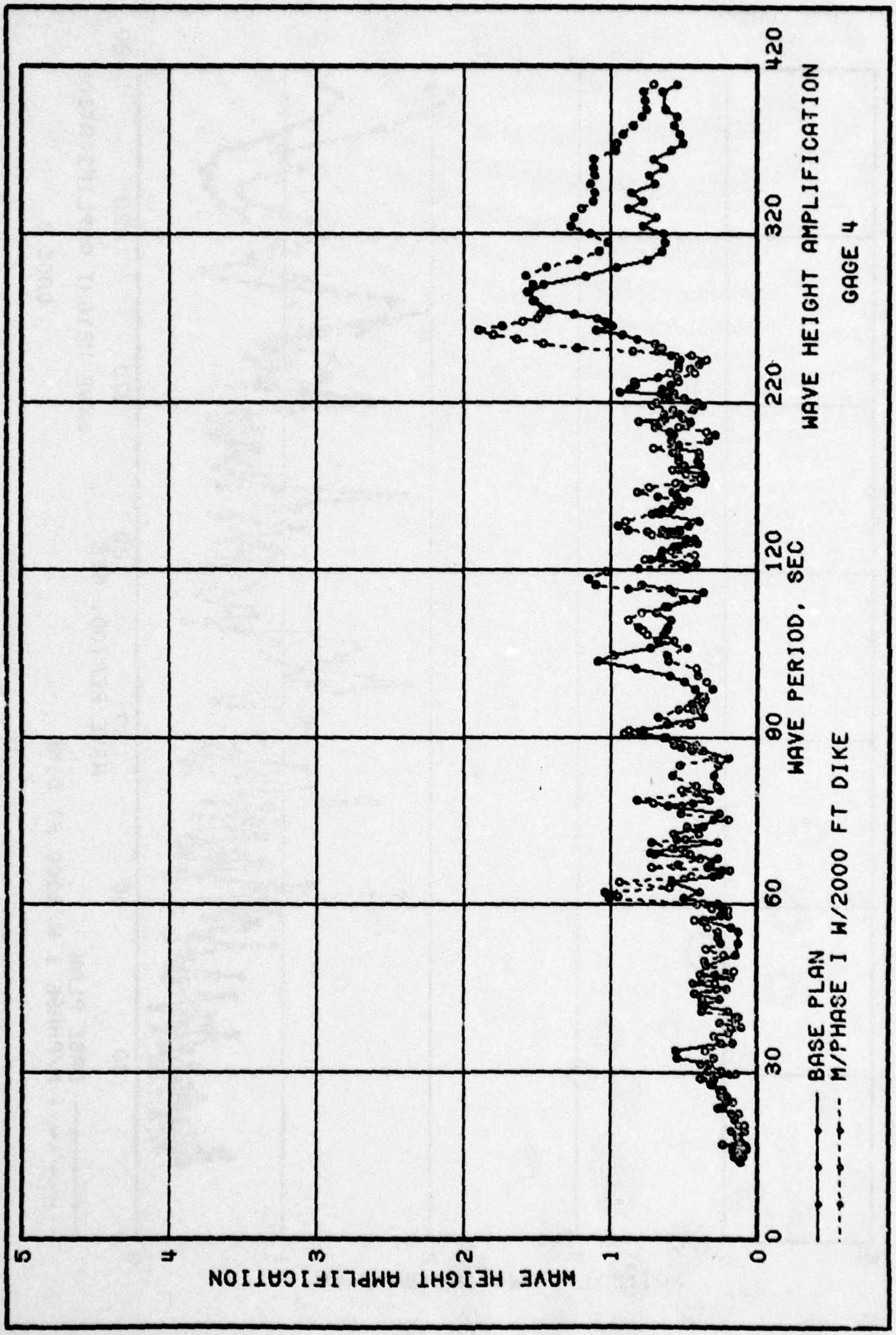
WAVE PERIOD, SEC
BASE PLAN
M/PHASE I W/2000 FT DIKE
WAVE HEIGHT AMPLIFICATION
GAGE 3

PLATE 5


WAVE HEIGHT AMPLIFICATION
GAGE 4
WAVE HEIGHT AMPLIFICATION
WAVE PERIOD, SEC
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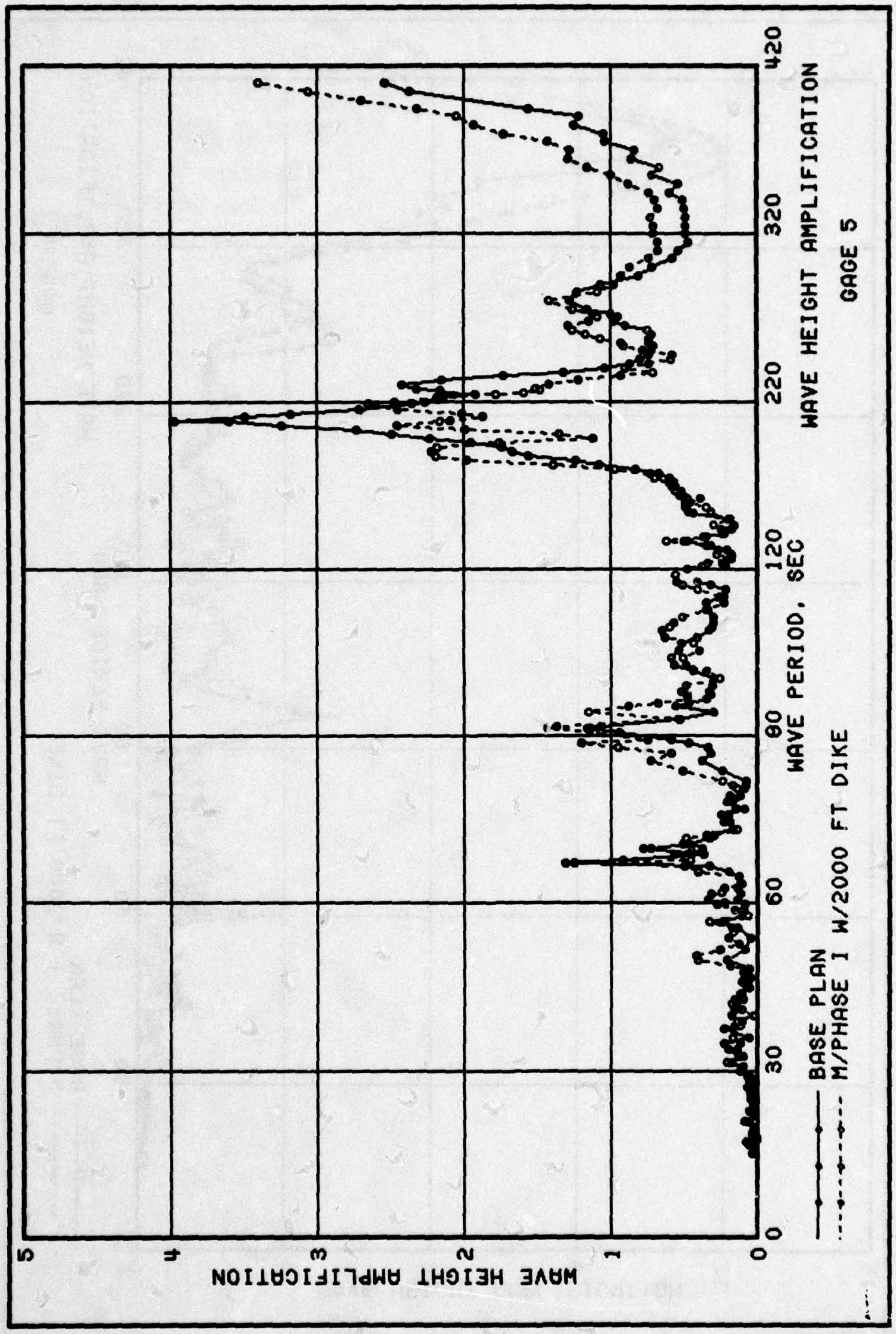
WAVE HEIGHT AMPLIFICATION
GAGE 5
WAVE HEIGHT AMPLIFICATION
WAVE PERIOD, SEC
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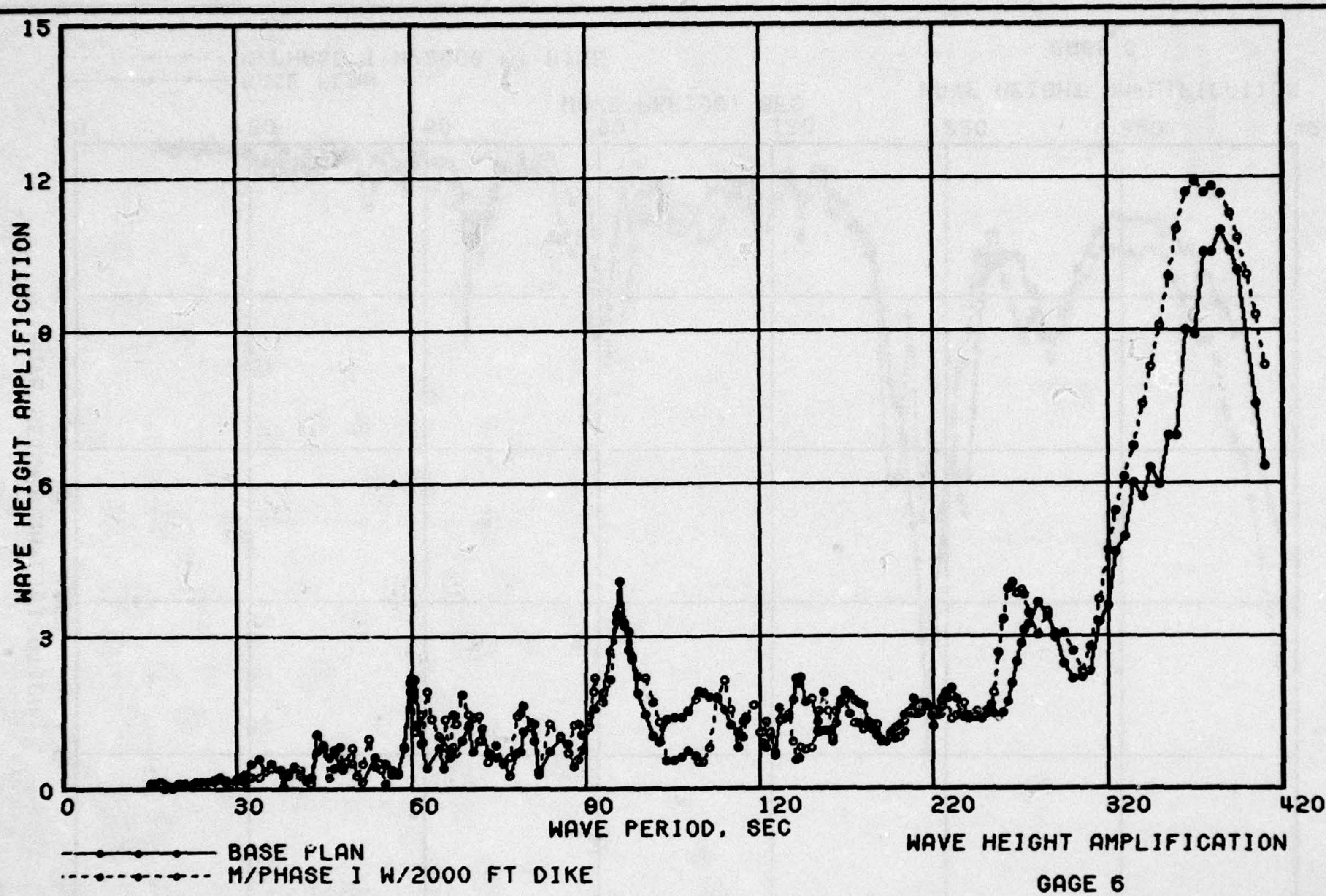
BASE PLAN
M/PHASE 1 W/2000 FT DIKE

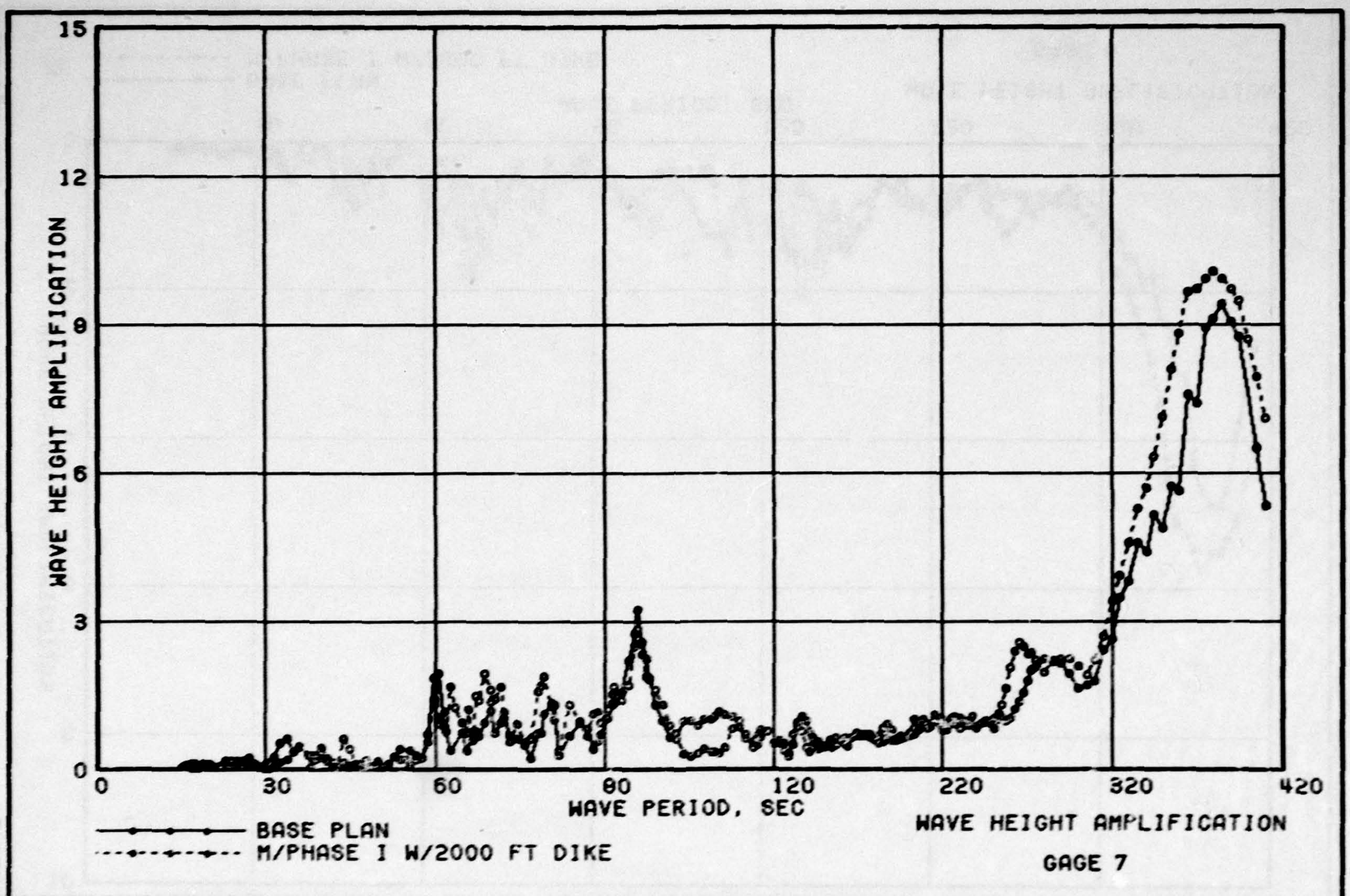
PLATE 7



WAVE HEIGHT AMPLIFICATION

GAGE 6

PLATE 8


WAVE HEIGHT AMPLIFICATION
15
12
9
6
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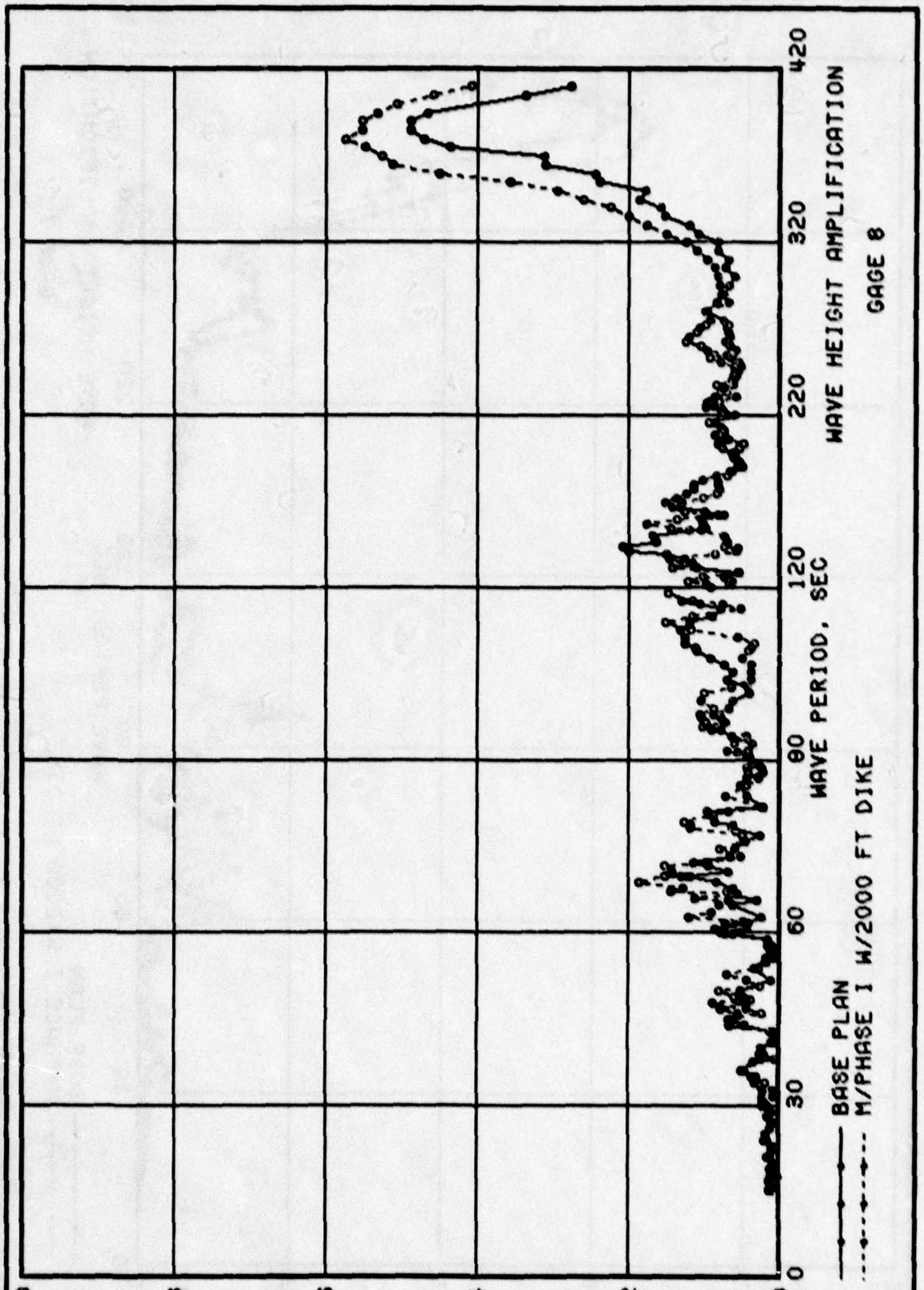
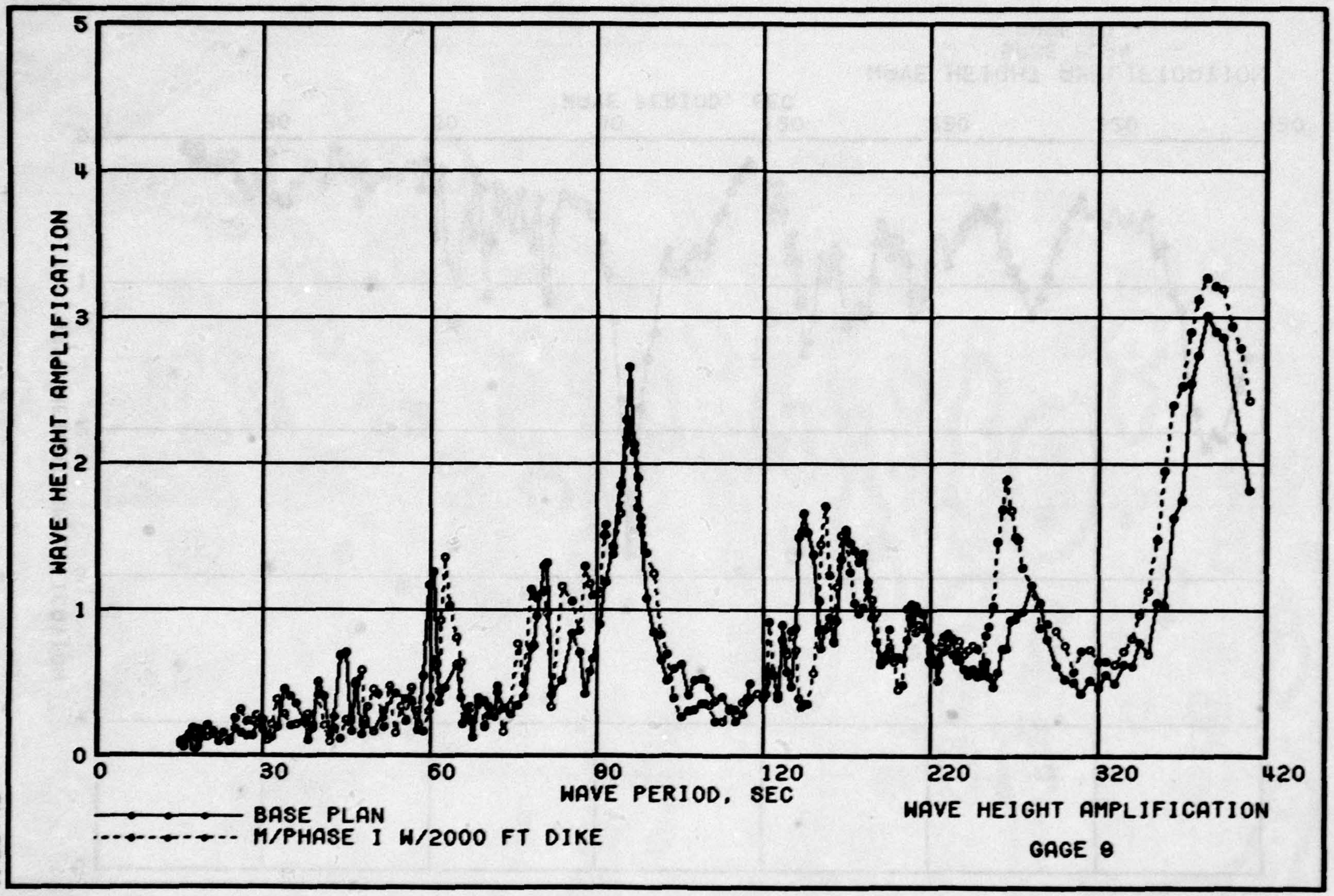
30
60
90
120
220
320
420
WAVE PERIOD, SEC
BASE PLAN
M/PHASE I W/2000 FT DIKE
WAVE HEIGHT AMPLIFICATION
GAGE 7

PLATE 9



WAVE HEIGHT AMPLIFICATION
GAGE 8
WAVE HEIGHT AMPLIFICATION
WAVE PERIOD, SEC
BASE PLAN
M/PHASE I W/2000 FT DIKE
0
2
4
6
8
10
0
30
60
90
120
220
320
420

PLATE 10


WAVE HEIGHT AMPLIFICATION
5
4
3
2
1
0
0
30
60
90
120
220
320
420
WAVE PERIOD, SEC
BASE PLAN
M/PHASE I W/2000 FT DIKE
WAVE HEIGHT AMPLIFICATION
GAGE 8

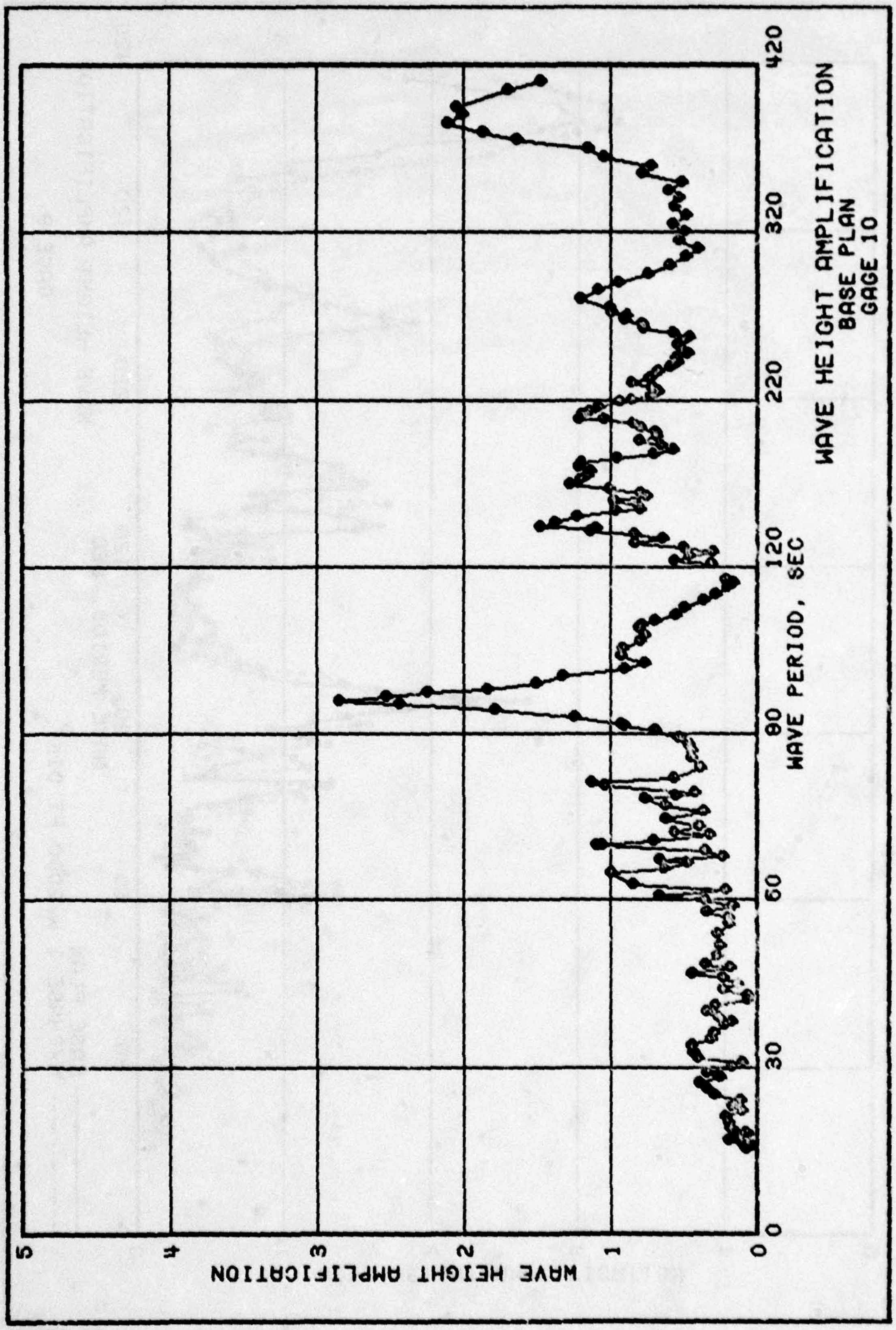

WAVE HEIGHT AMPLIFICATION
0
1
2
3
4
5
WAVE PERIOD, SEC
0
30
60
90
120
220
320
420
WAVE HEIGHT AMPLIFICATION
BASE PLAN
GAGE 10

PLATE 12

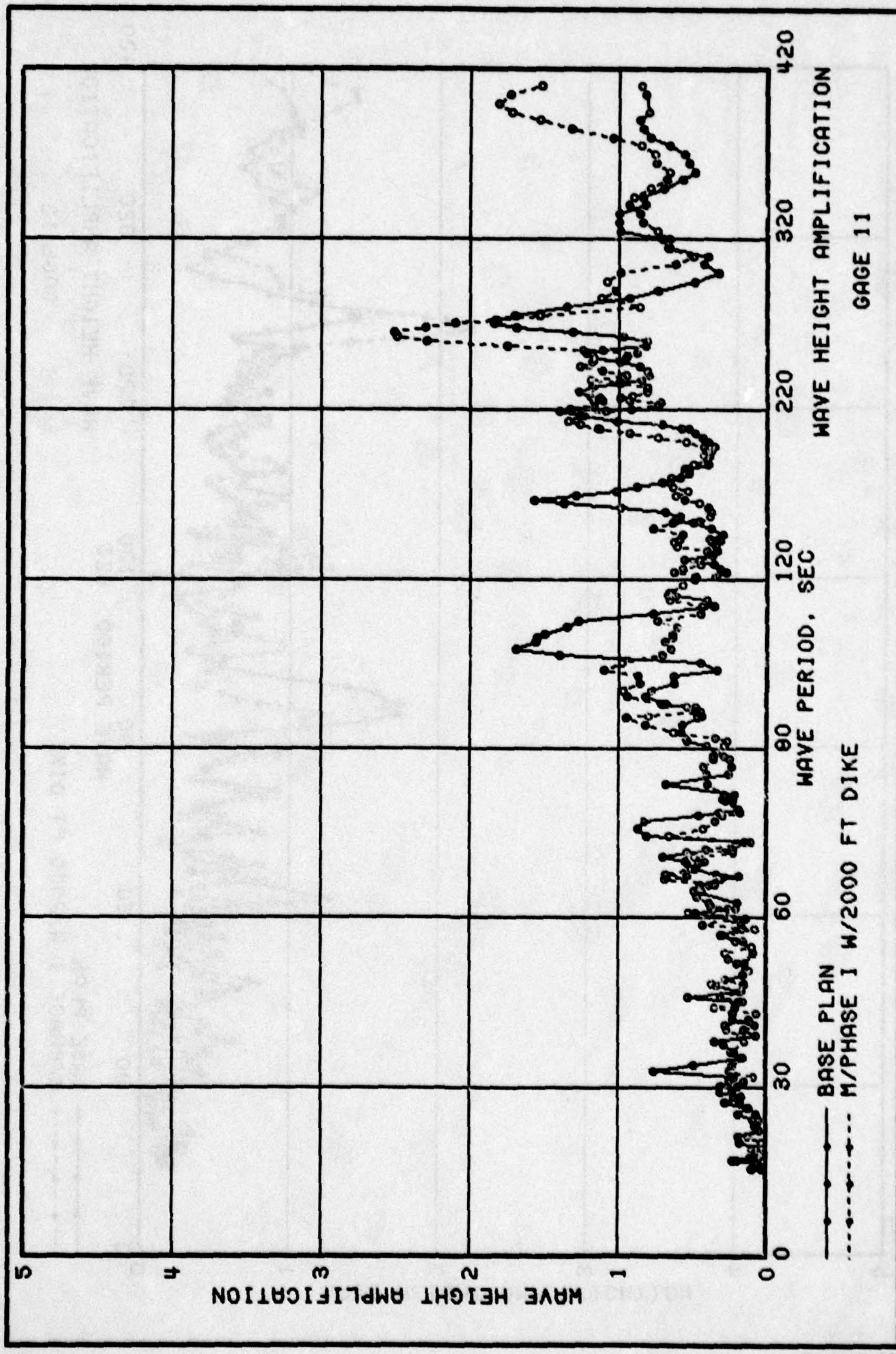

WAVE HEIGHT AMPLIFICATION
GAGE 11
WAVE HEIGHT AMPLIFICATION
WAVE PERIOD, SEC
0
30
60
90
120
220
320
420
0
1
2
3
4
5
BASE PLAN
M/PHASE I W/2000 FT DIKE

PLATE 13

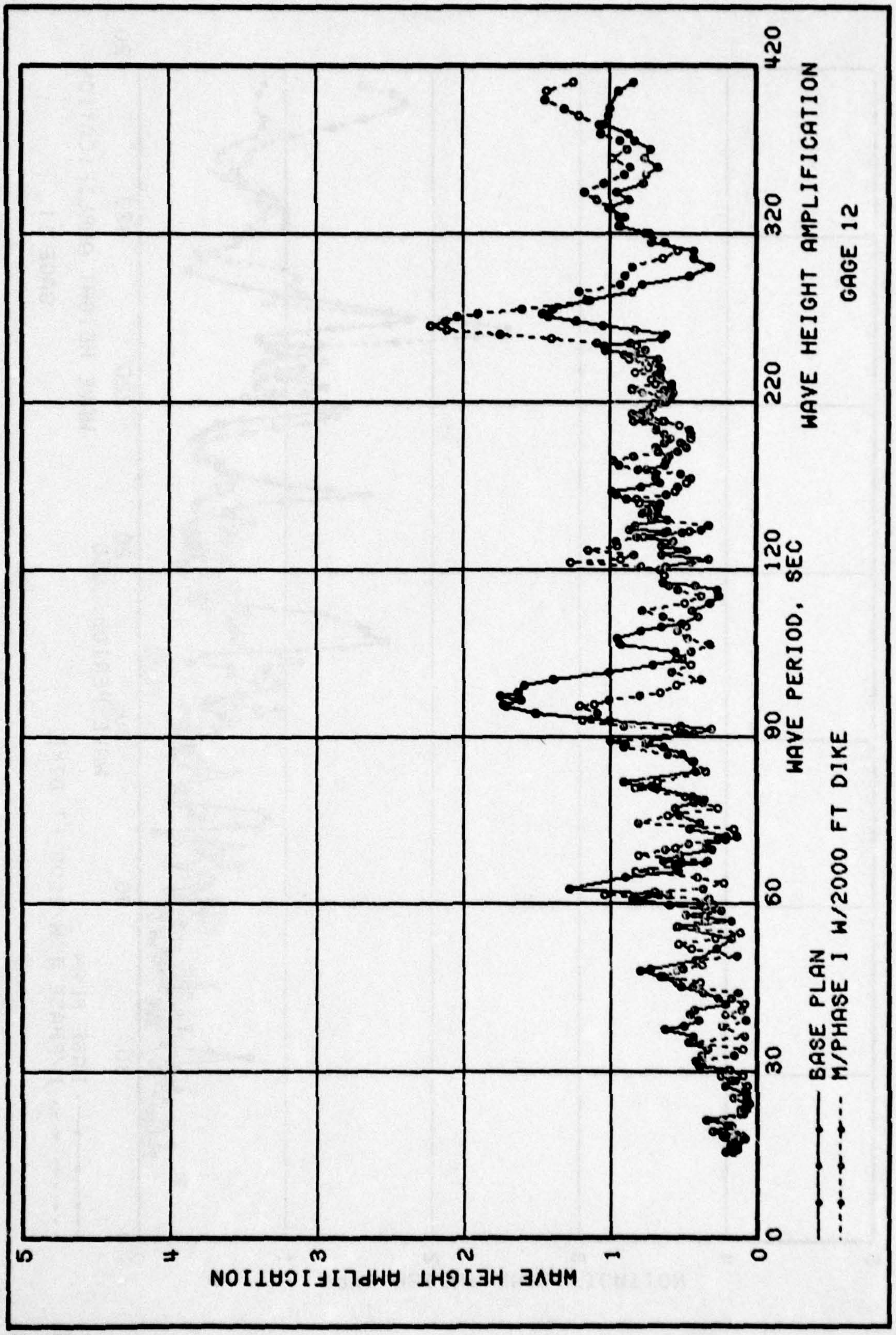

WAVE HEIGHT AMPLIFICATION
GAGE 12
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
BASE PLAN
M/PHASE I W/2000 FT DIKE
0
30
60
90
120
220
320
420
0
1
2
3
4
5

PLATE 14

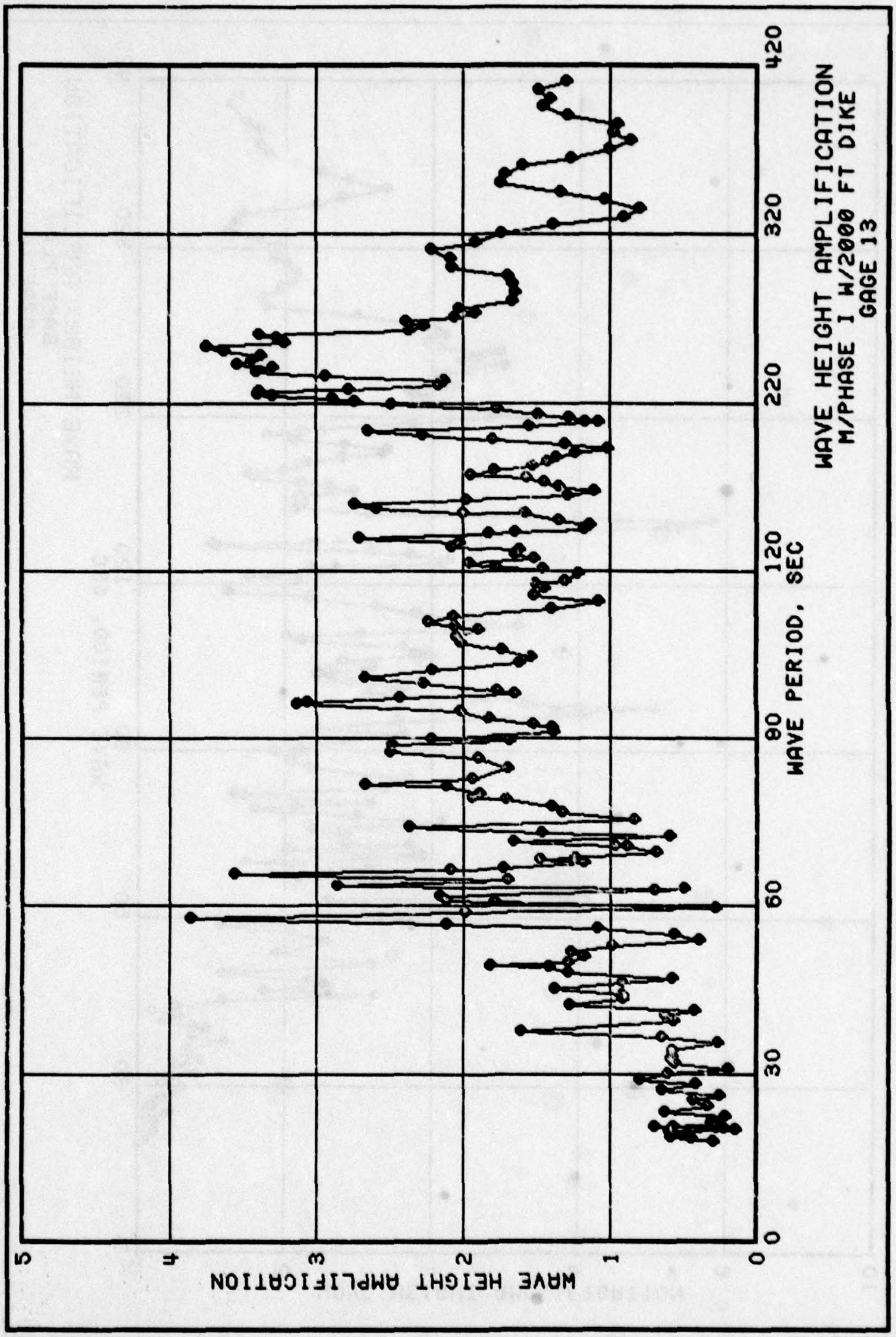

WAVE HEIGHT AMPLIFICATION
M/PHASE I W/2000 FT DIKE
GAGE 13
WAVE HEIGHT AMPLIFICATION
WAVE PERIOD, SEC
0
1
2
3
4
5
0
30
60
90
120
220
320
420

PLATE 15

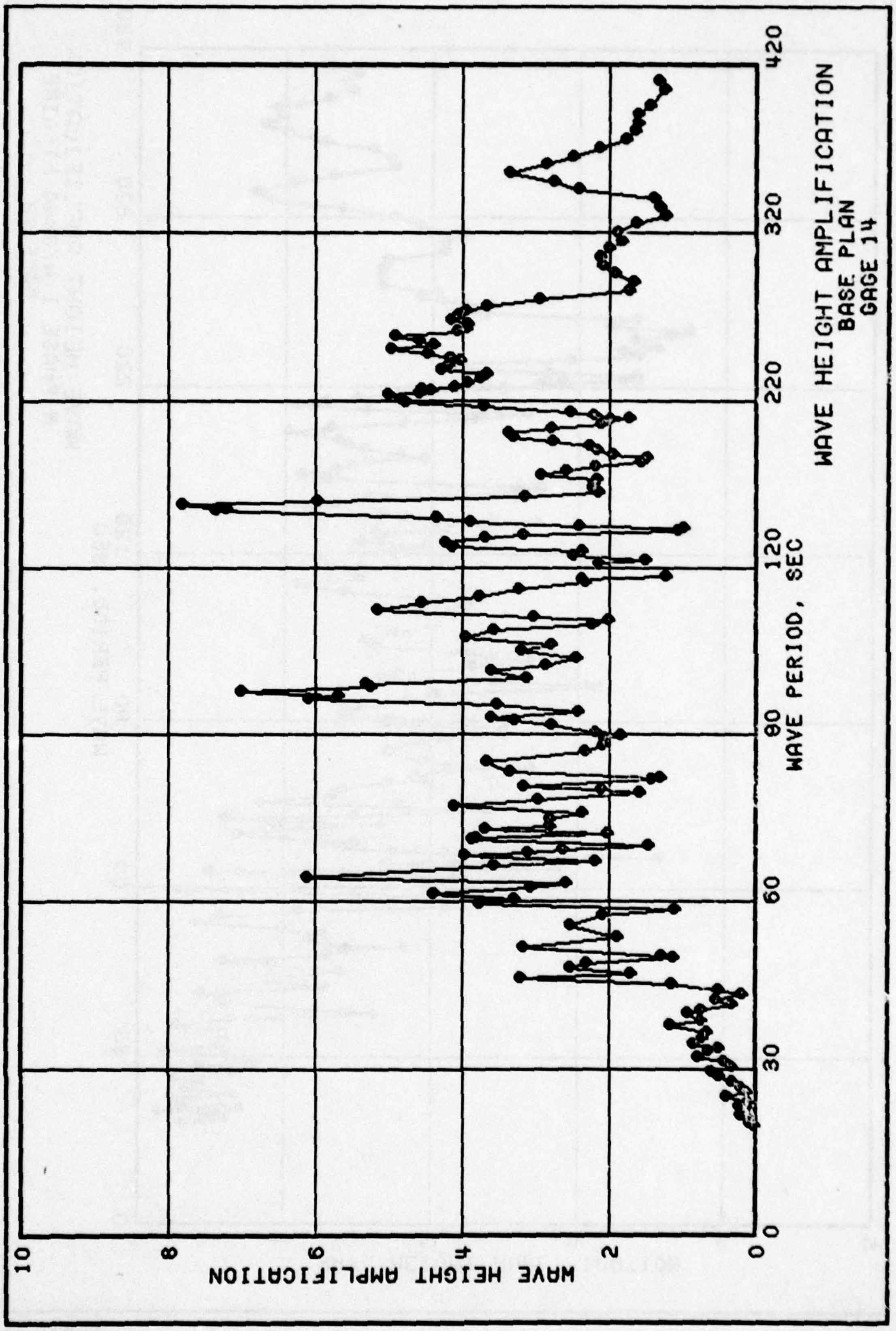
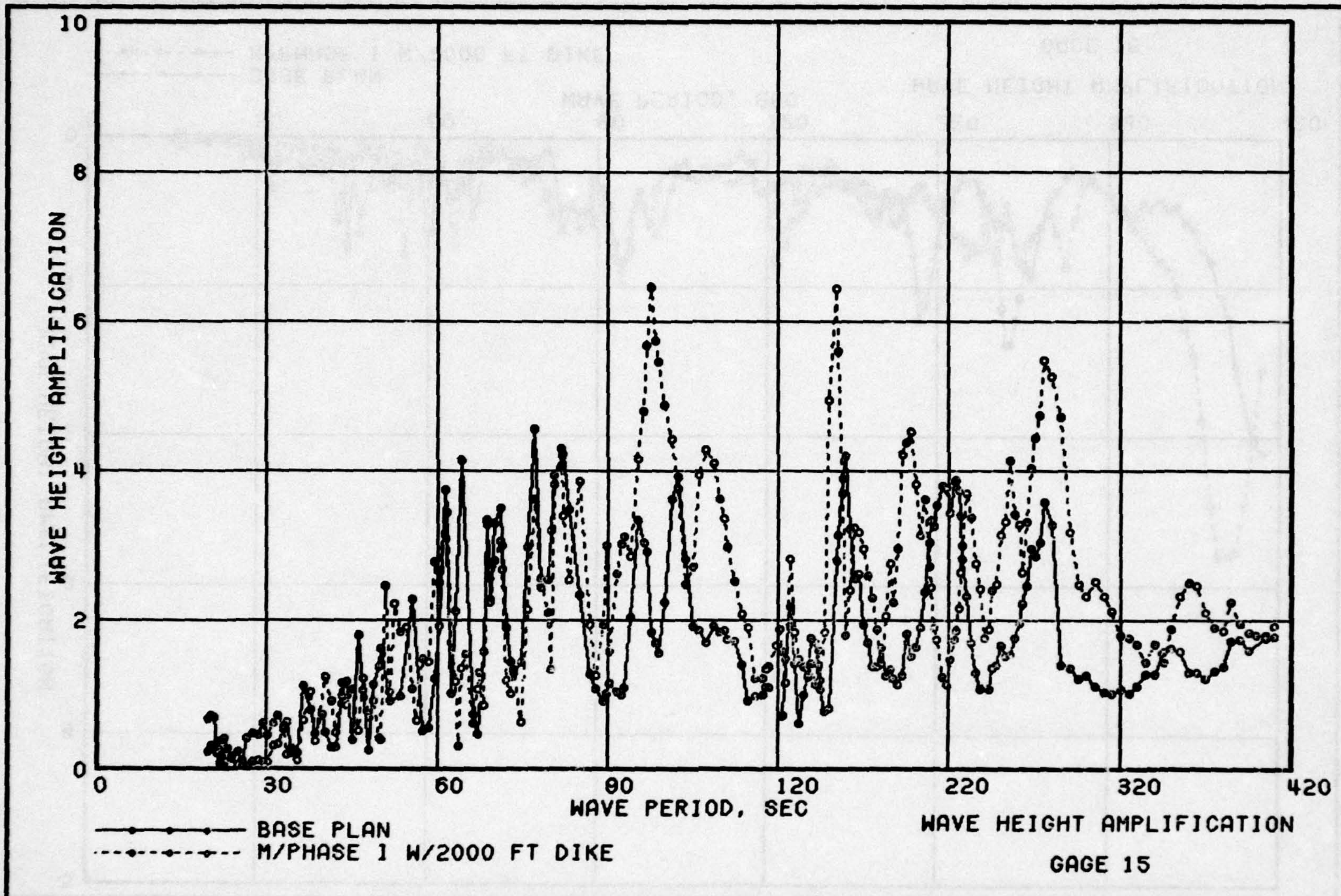

WAVE HEIGHT AMPLIFICATION
BASE PLAN
GAGE 14
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
0
30
60
90
120
220
320
420
0
2
4
6
8
10

PLATE 16



WAVE HEIGHT AMPLIFICATION
0
2
4
6
8
10
0
30
60
90
120
220
320
420
WAVE PERIOD, SEC
BASE PLAN
M/PHASE 1 W/2000 FT DIKE
WAVE HEIGHT AMPLIFICATION
GAGE 15

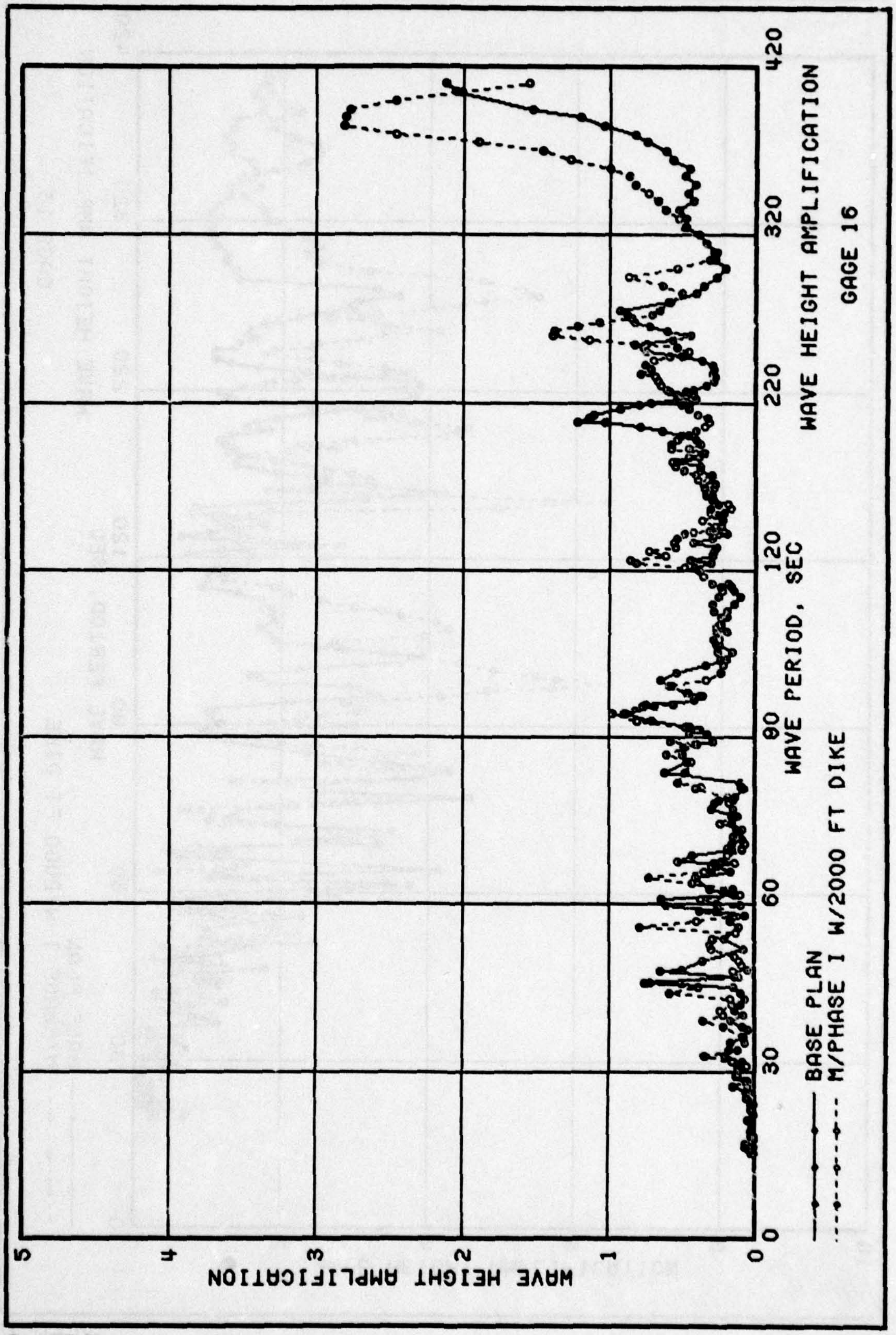
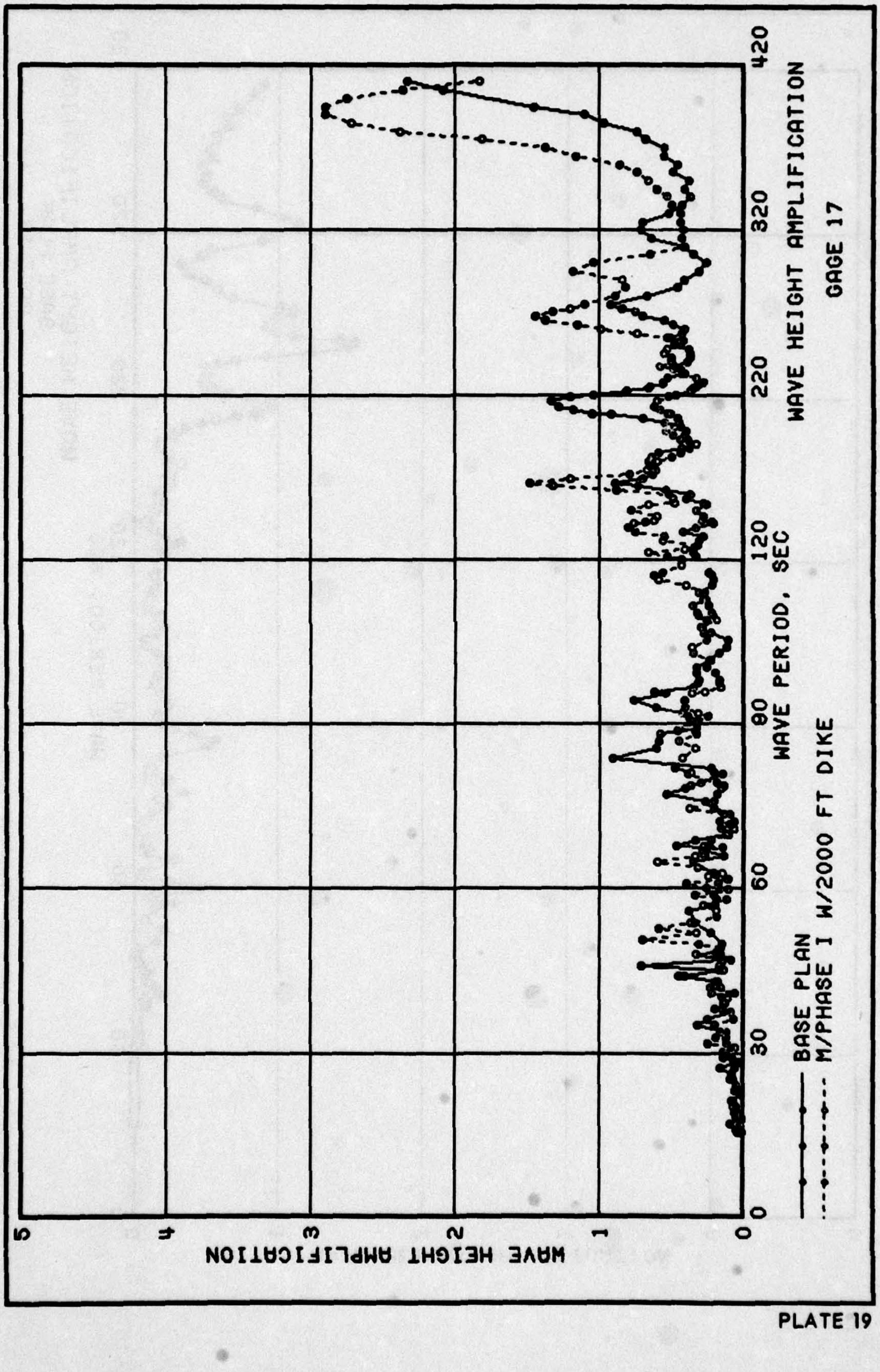

WAVE HEIGHT AMPLIFICATION
GAGE 16
WAVE HEIGHT AMPLIFICATION
WAVE PERIOD, SEC
BASE PLAN
M/PHASE I W/2000 FT DIKE
0
1
2
3
4
5
0
30
60
90
120
220
320
420

PLATE 18


WAVE HEIGHT AMPLIFICATION
GAGE 17
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
BASE PLAN
M/PHASE I W/2000 FT DIKE
0
30
60
90
120
220
320
420
0
1
2
3
4
5

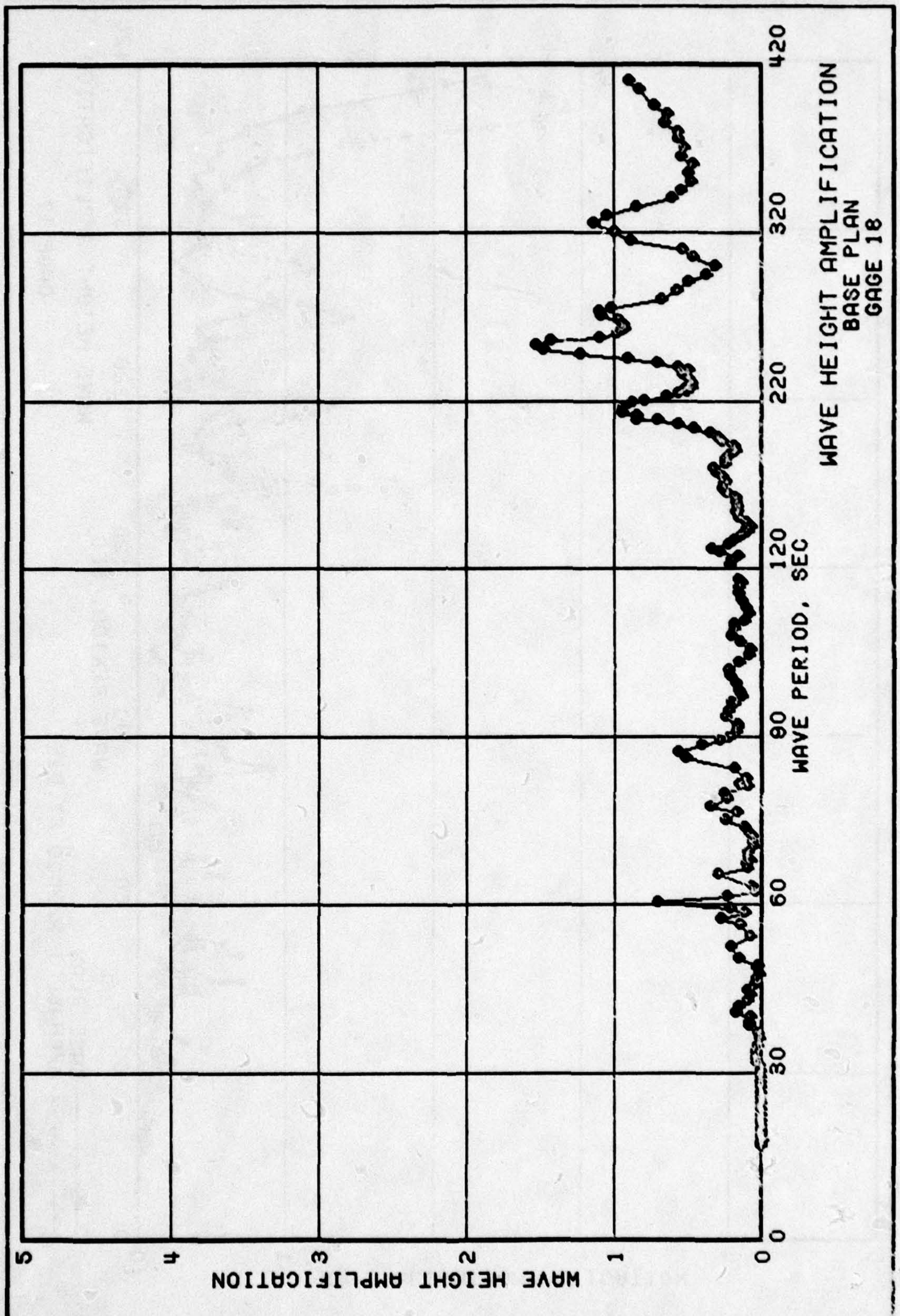
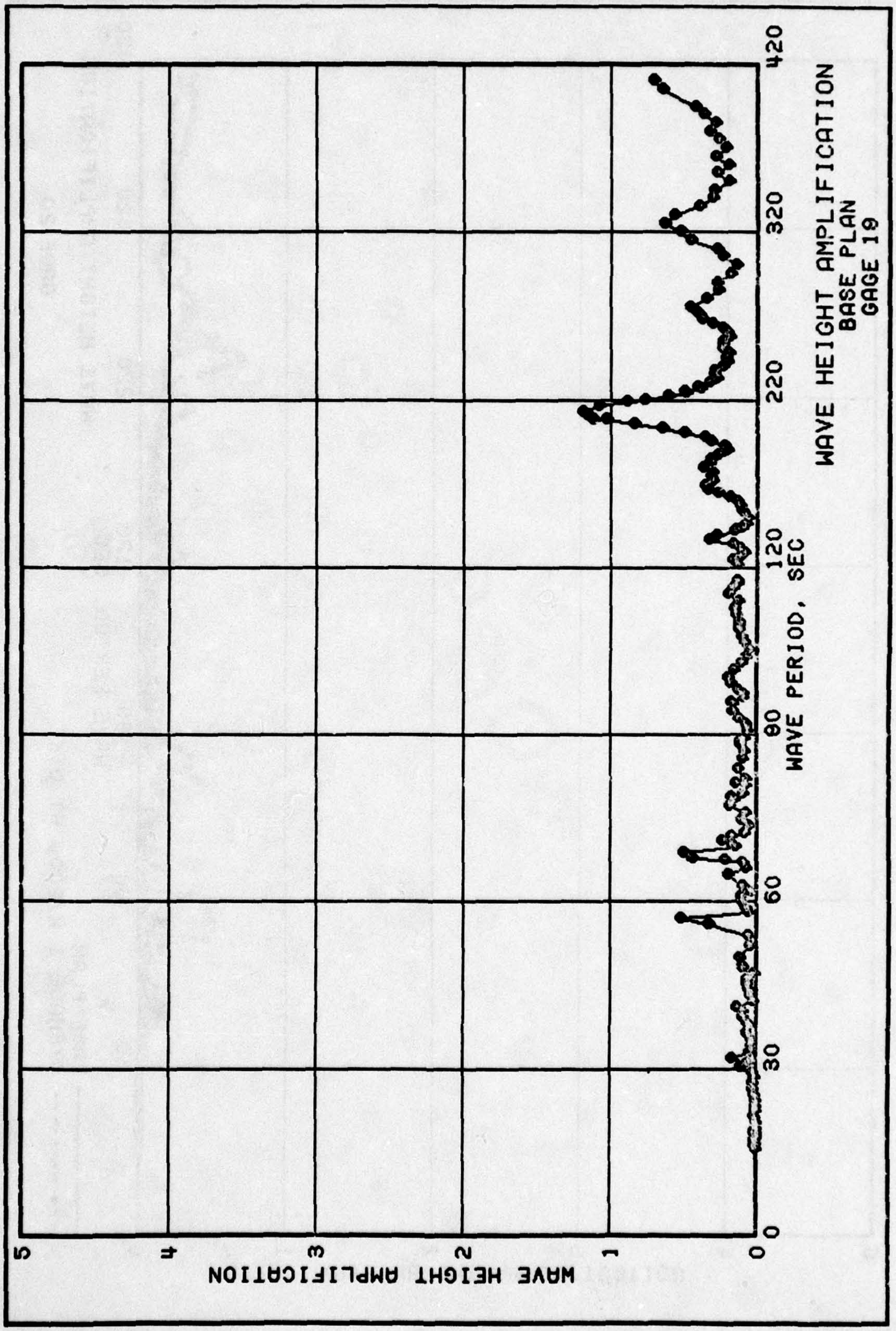
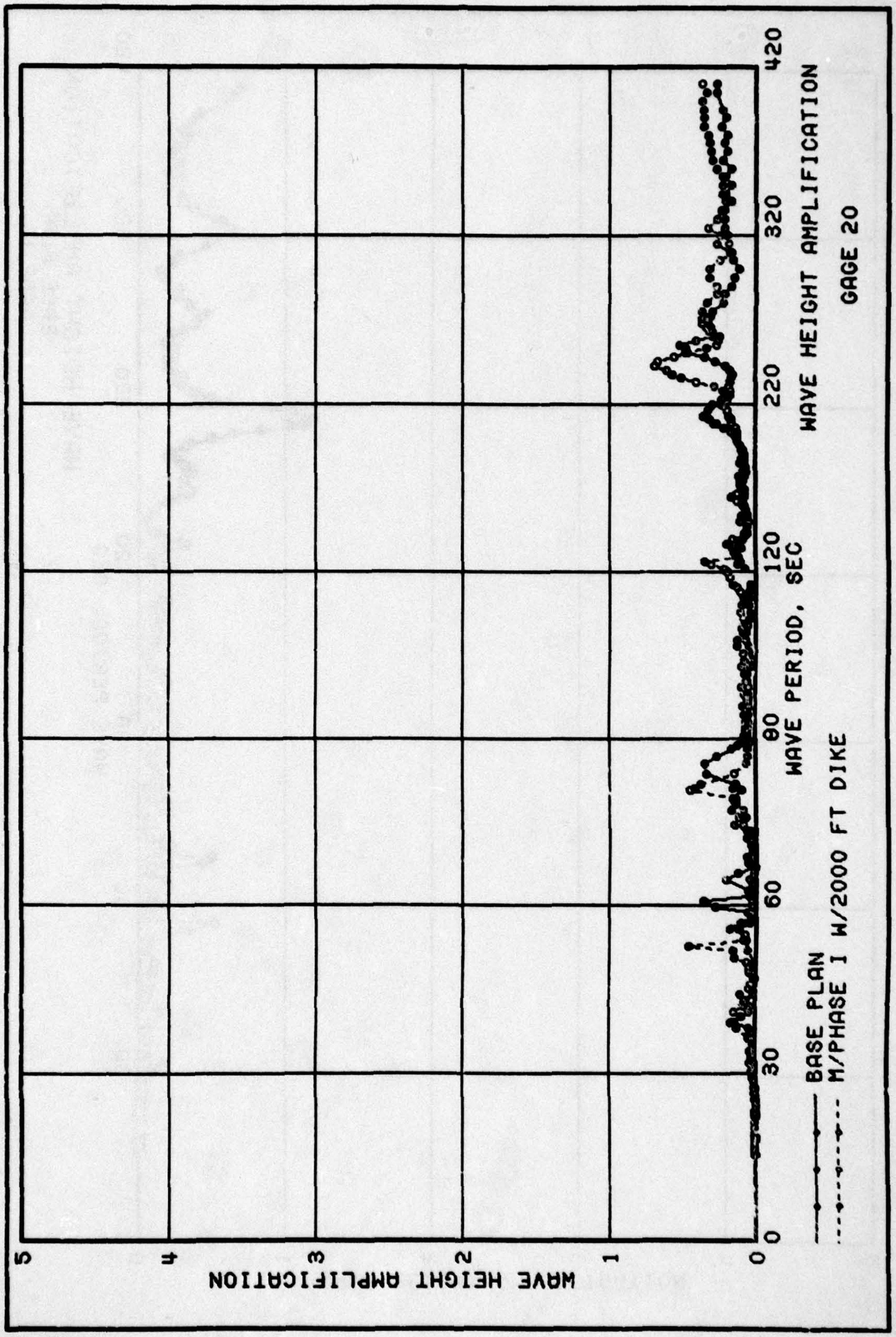

WAVE HEIGHT AMPLIFICATION
BASE PLAN
GAGE 18
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
0
30
60
90
120
220
320
420
0
1
2
3
4
5

PLATE 20



WAVE HEIGHT AMPLIFICATION
BASE PLAN
GAGE 19
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
0
30
60
90
120
220
320
420
0
1
2
3
4
5

PLATE 21



WAVE HEIGHT AMPLIFICATION
GAGE 20
WAVE HEIGHT AMPLIFICATION
WAVE PERIOD, SEC
BASE PLAN
W/PHASE I W/2000 FT DIKE
0
1
2
3
4
5
0
30
60
90
120
220
320
420

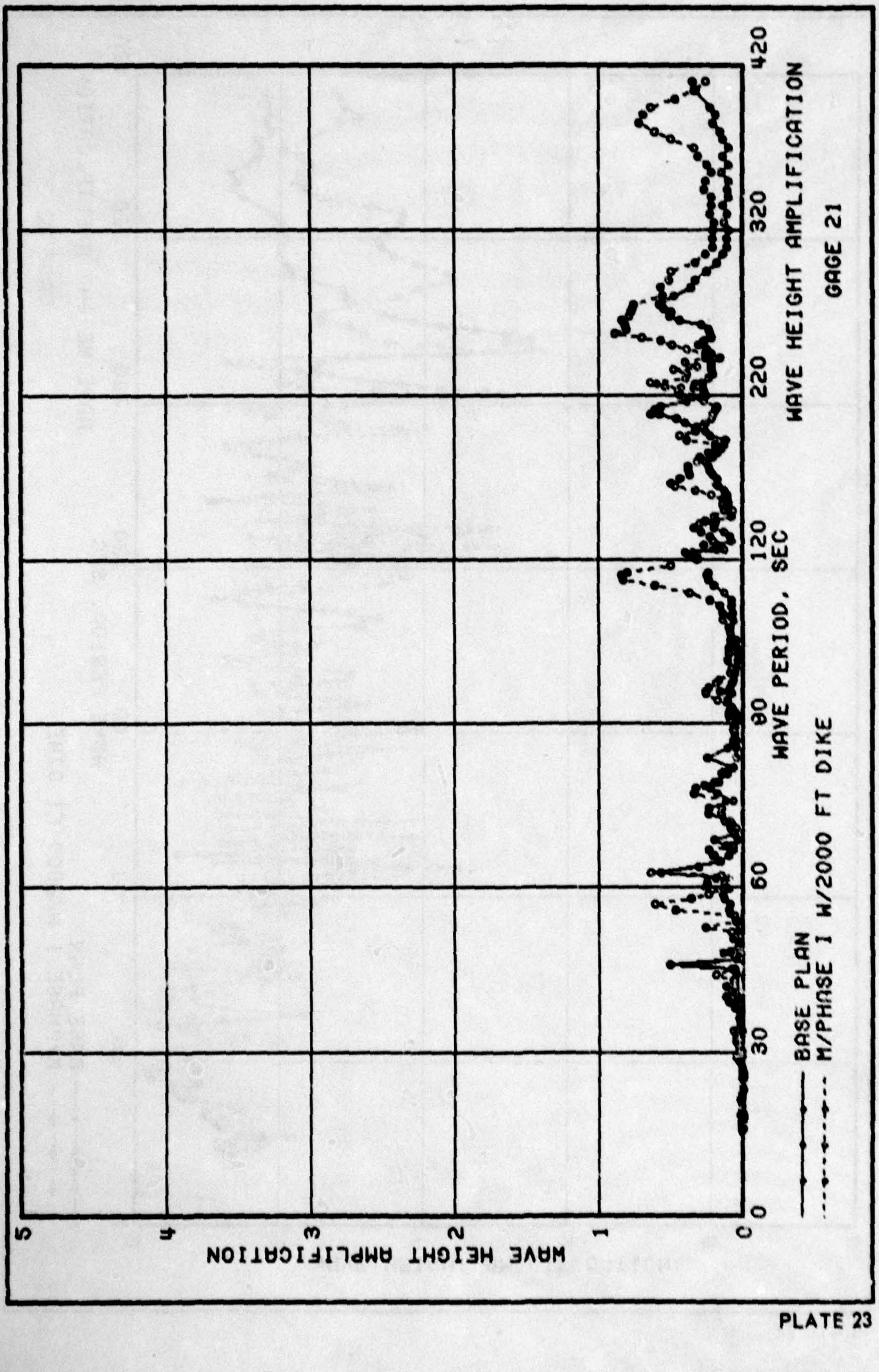
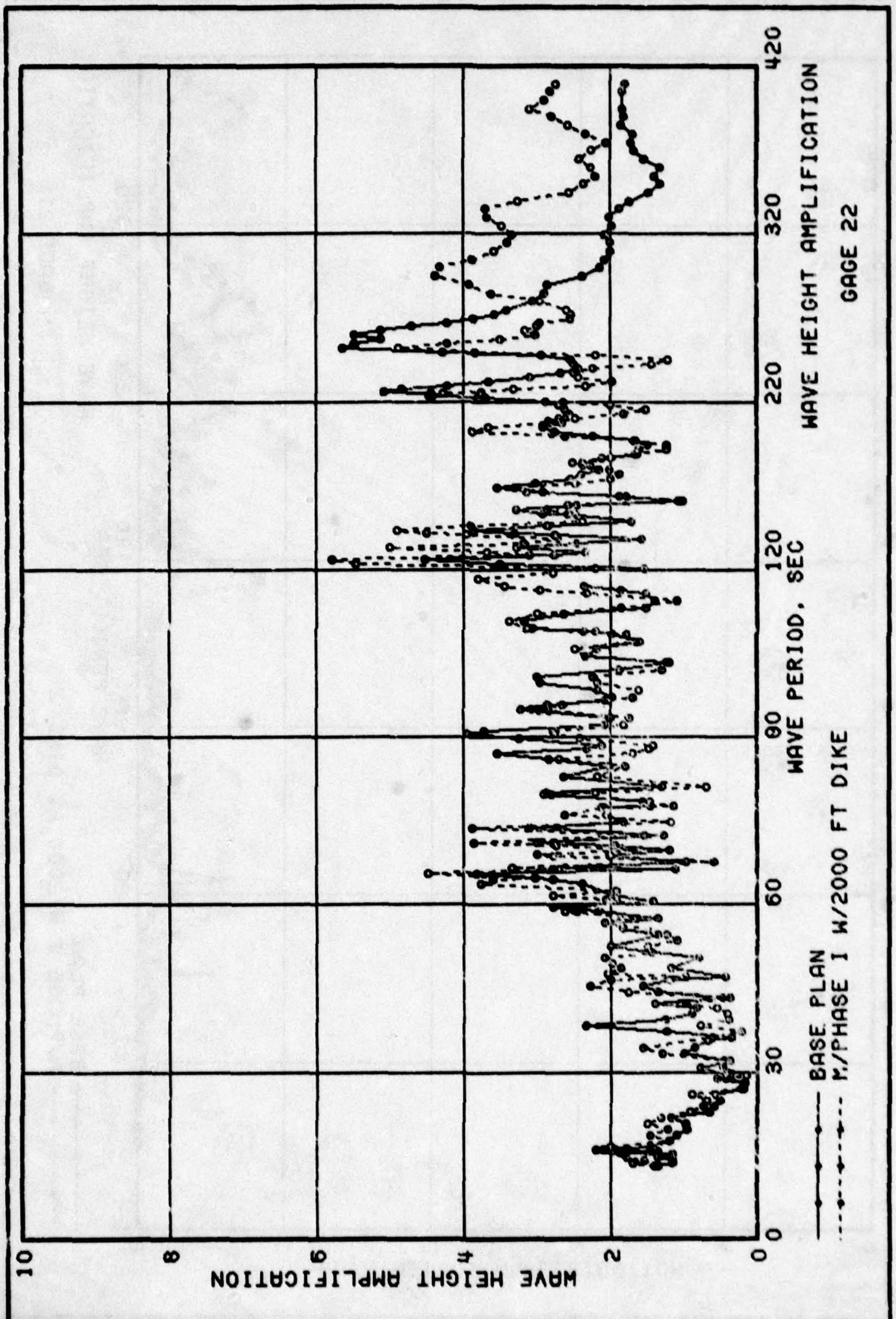
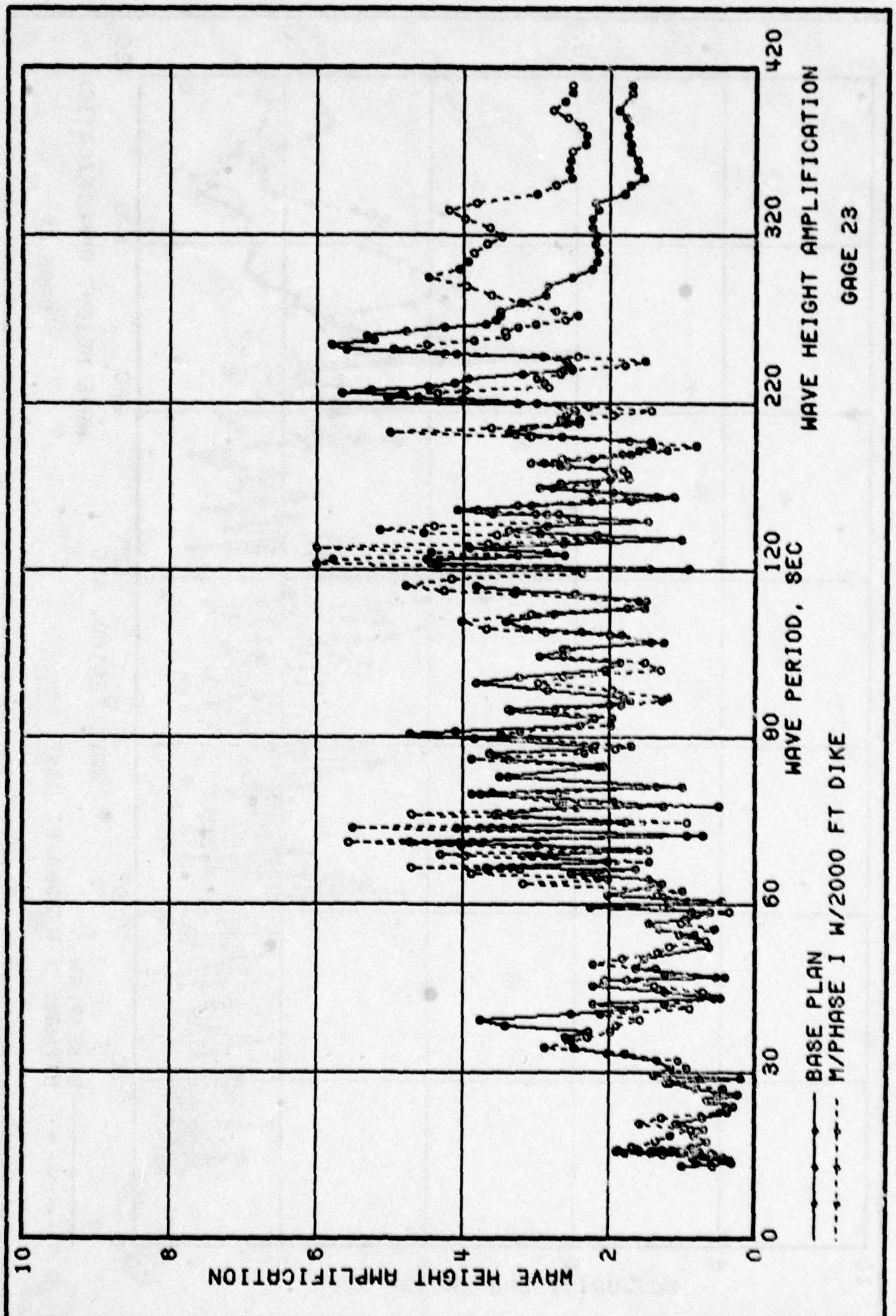

WAVE HEIGHT AMPLIFICATION
GAGE 21
WAVE HEIGHT AMPLIFICATION
0
1
2
3
4
5
0
30
60
90
120
220
320
420
WAVE PERIOD, SEC
BASE PLAN
W/PHASE I W/2000 FT DIKE

PLATE 23

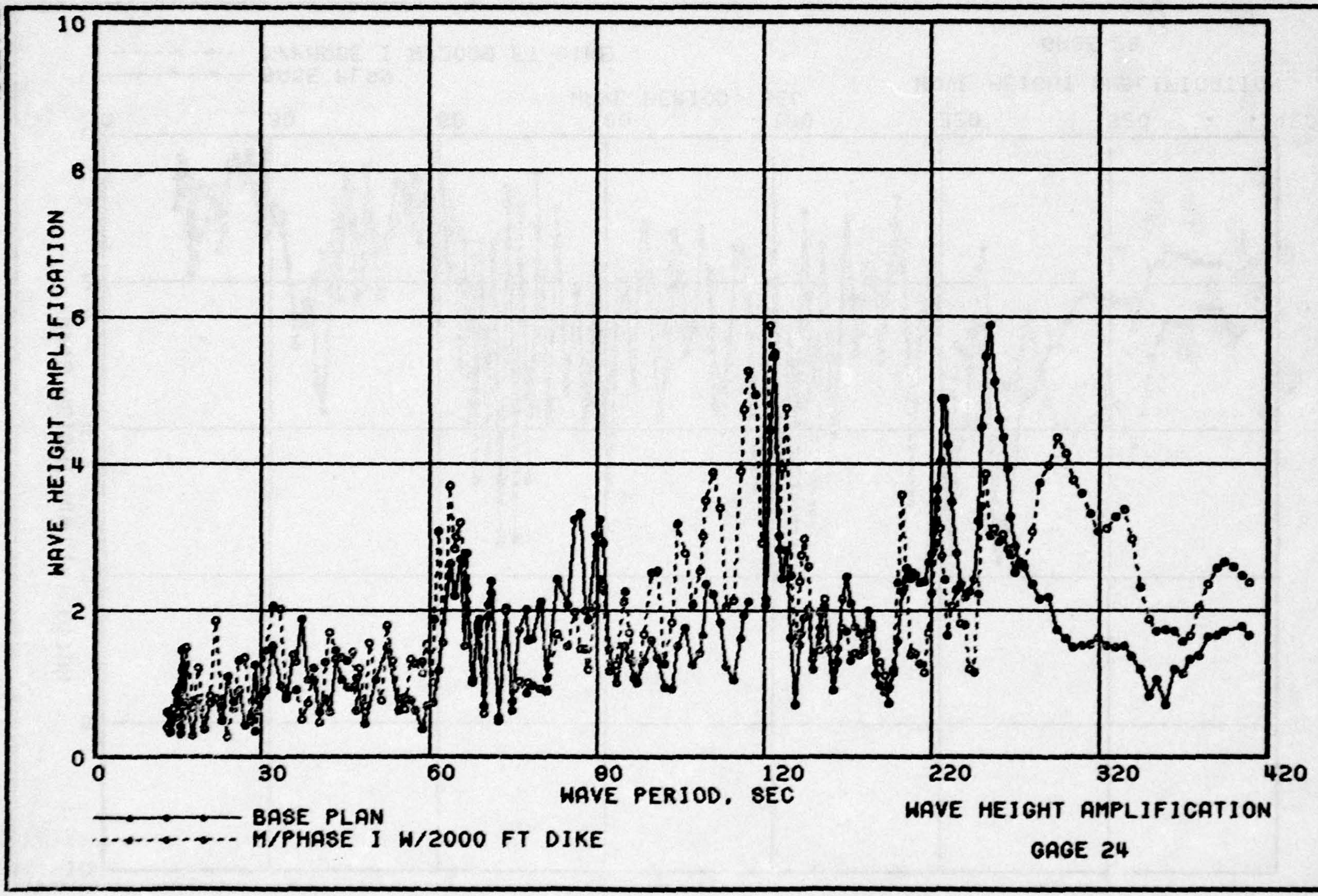


WAVE HEIGHT AMPLIFICATION
GAGE 22
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
0
2
4
6
8
10
0
30
60
90
120
220
320
420
BASE PLAN
W/PHASE I W/2000 FT DIKE

PLATE 24



WAVE HEIGHT AMPLIFICATION
GAGE 23
WAVE HEIGHT AMPLIFICATION
WAVE PERIOD, SEC
0
30
60
90
120
220
320
420
0
2
4
6
8
10
BASE PLAN
M/PHASE I W/2000 FT DIKE


WAVE HEIGHT AMPLIFICATION
0
2
4
6
8
10
0
30
60
90
120
220
320
420
WAVE PERIOD, SEC
BASE PLAN
M/PHASE I W/2000 FT DIKE
WAVE HEIGHT AMPLIFICATION
GAGE 24

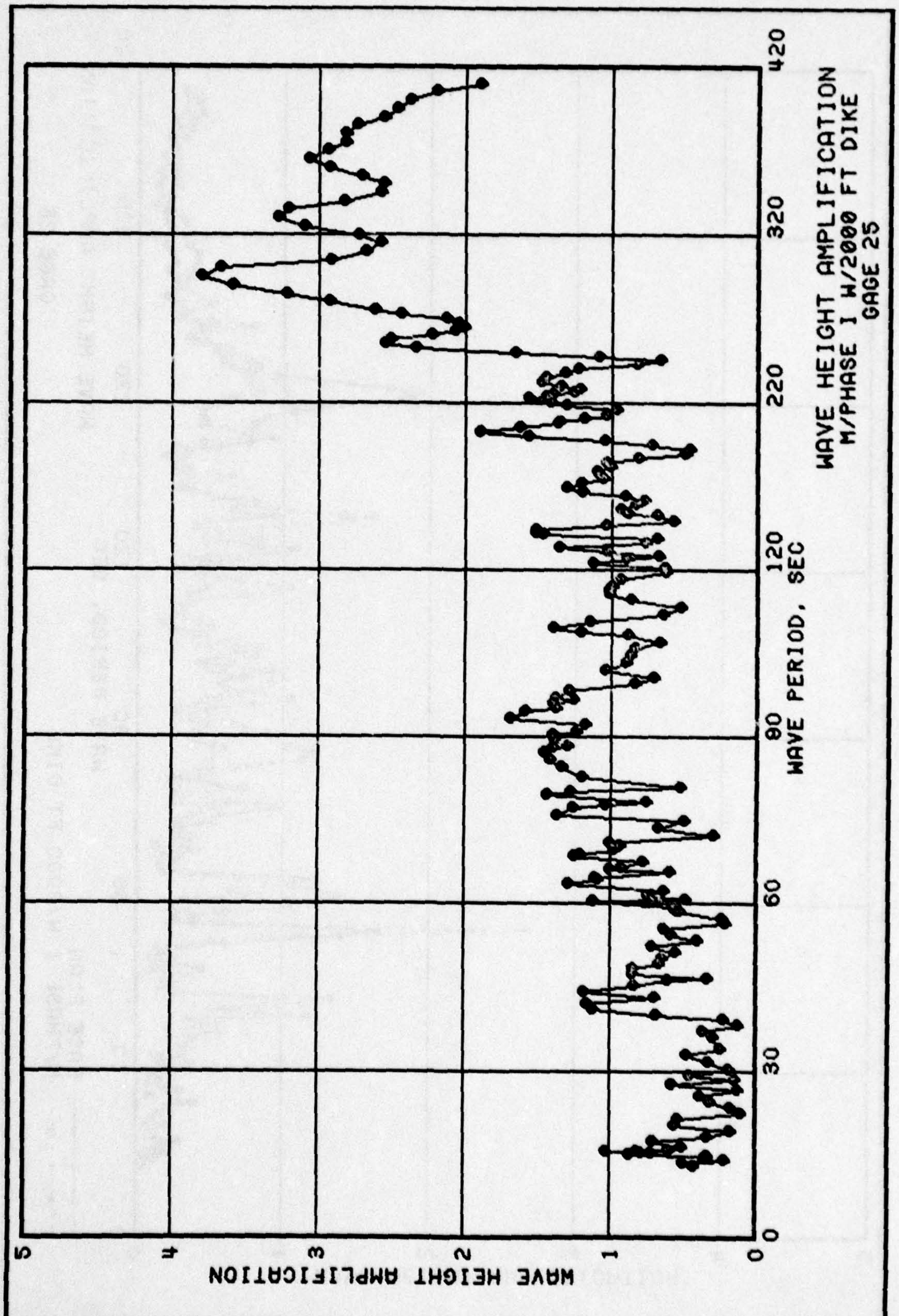
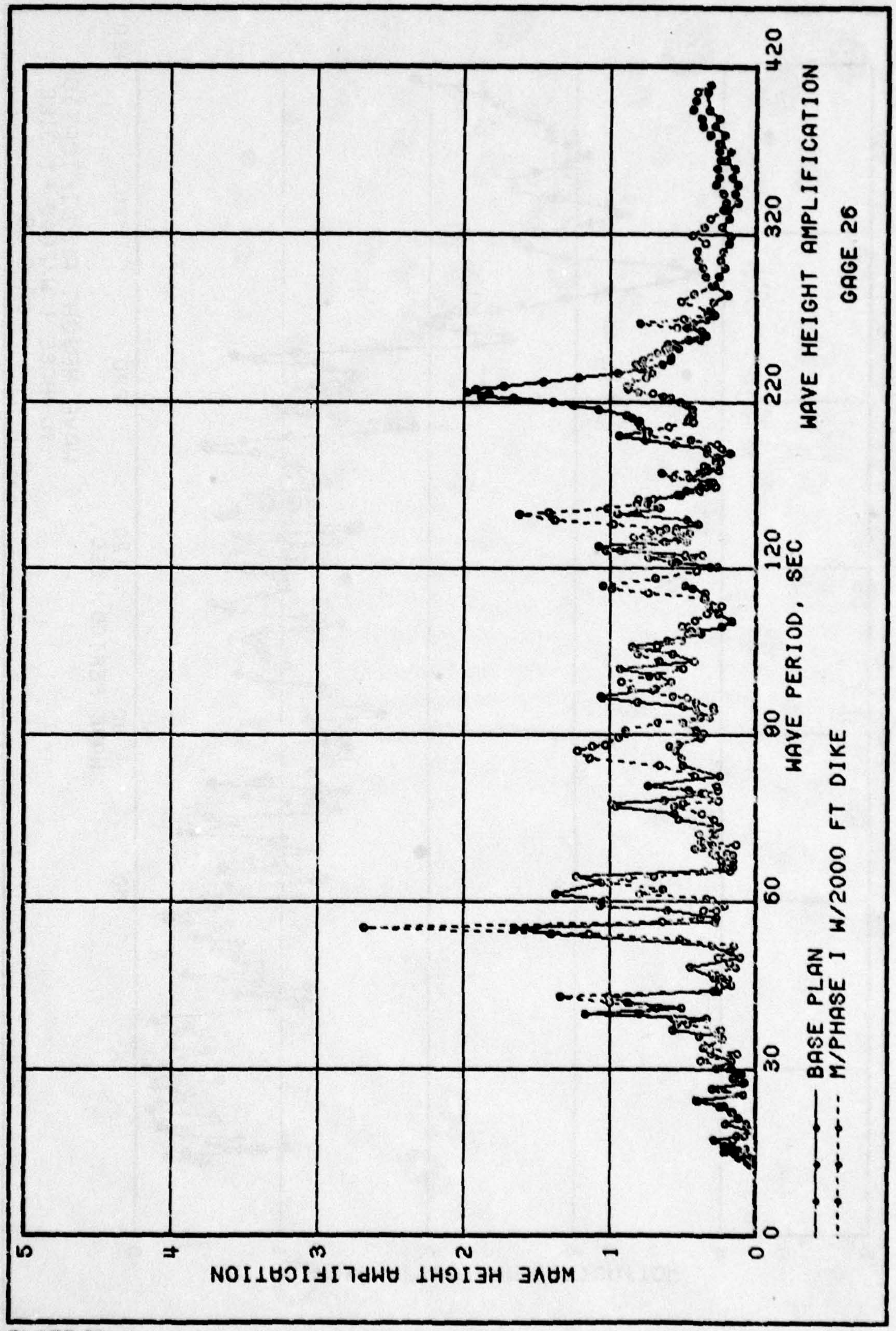

WAVE HEIGHT AMPLIFICATION
M/PHASE I W/2000 FT DIKE
GAGE 25
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
0
30
60
90
120
220
320
420
0
1
2
3
4
5

PLATE 27



WAVE HEIGHT AMPLIFICATION
GAGE 26
WAVE HEIGHT AMPLIFICATION
0
1
2
3
4
5
WAVE PERIOD, SEC
0
30
60
90
120
220
320
420
BASE PLAN
M/PHASE I W/2000 FT DIKE

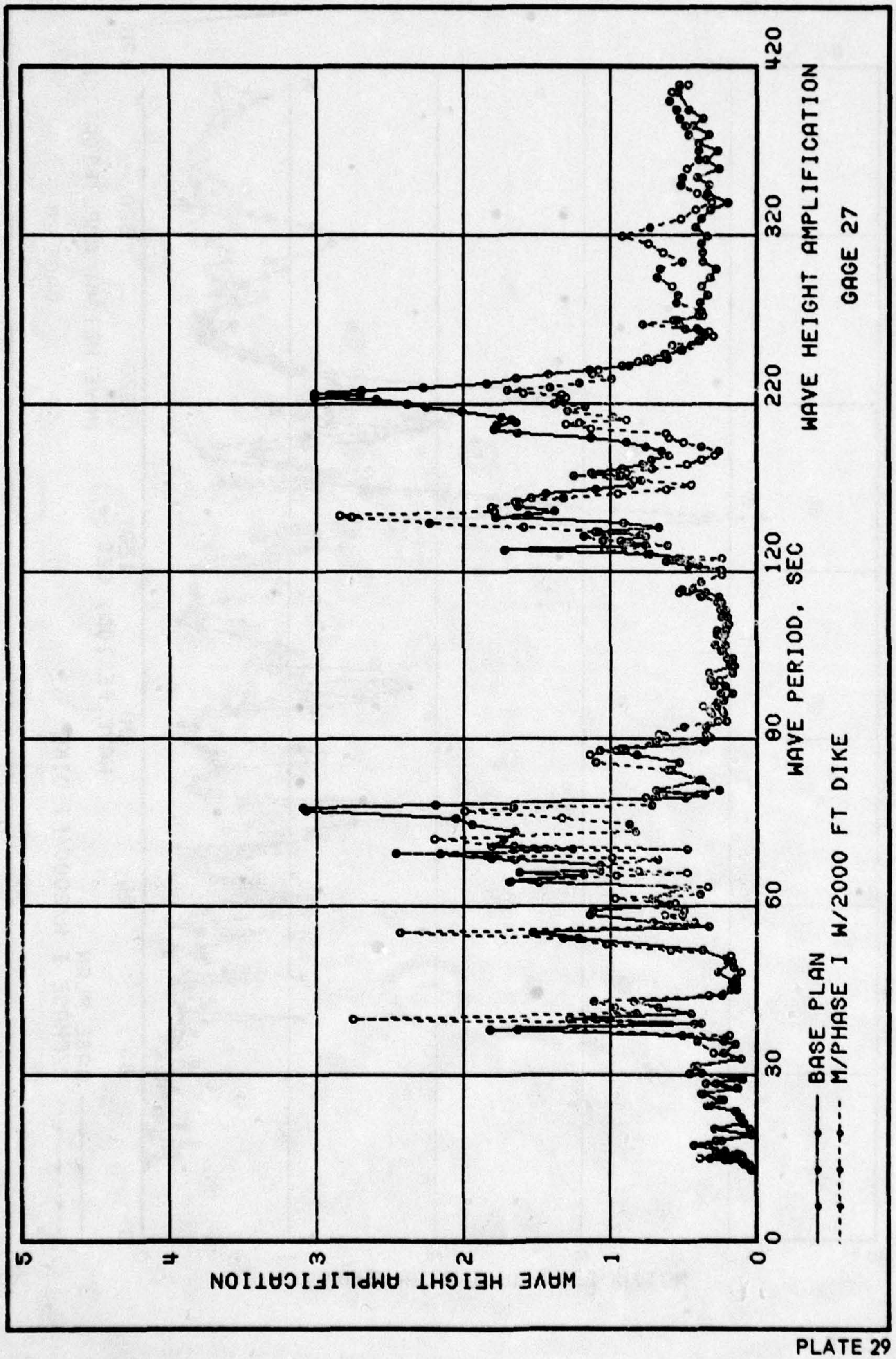

WAVE HEIGHT AMPLIFICATION
GAGE 27
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
BASE PLAN
M/PHASE I W/2000 FT DIKE
0
30
60
90
120
220
320
420
0
1
2
3
4
5

PLATE 29

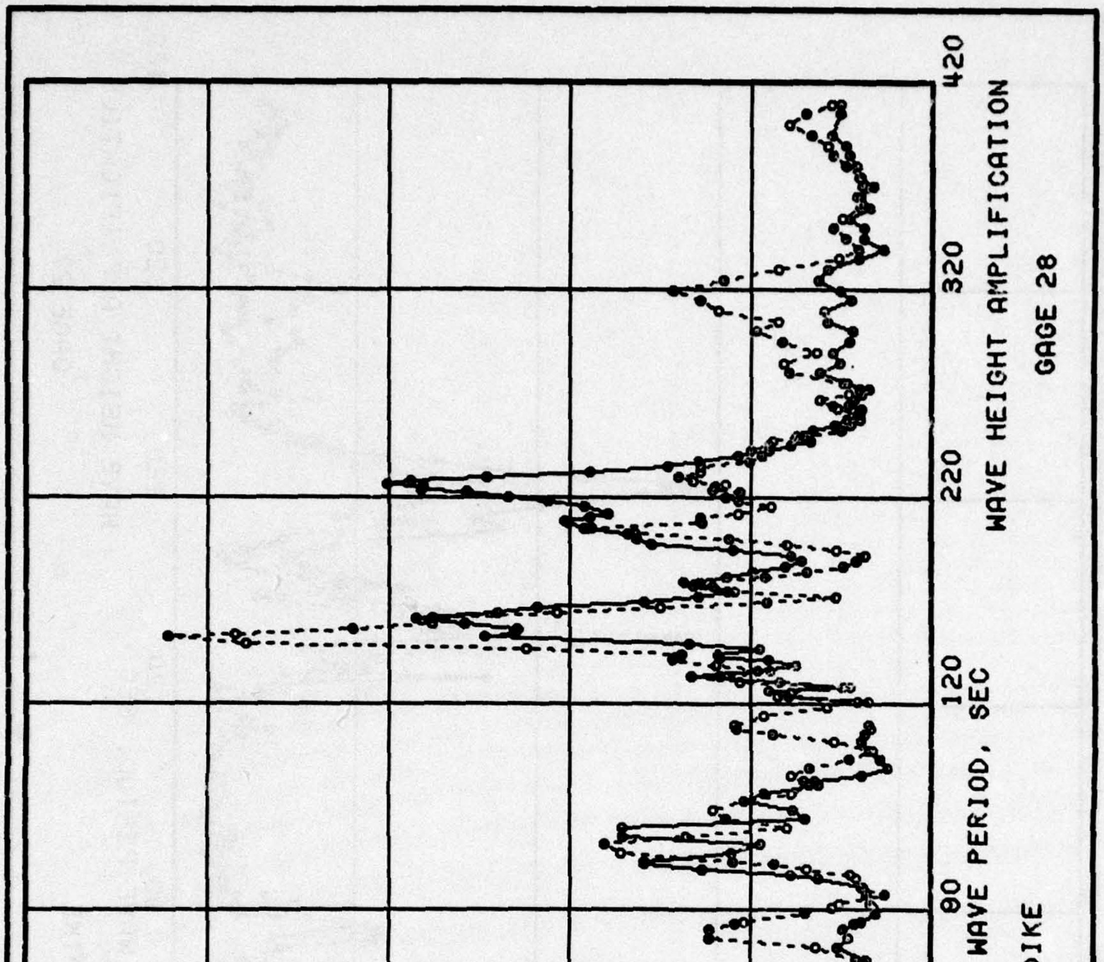
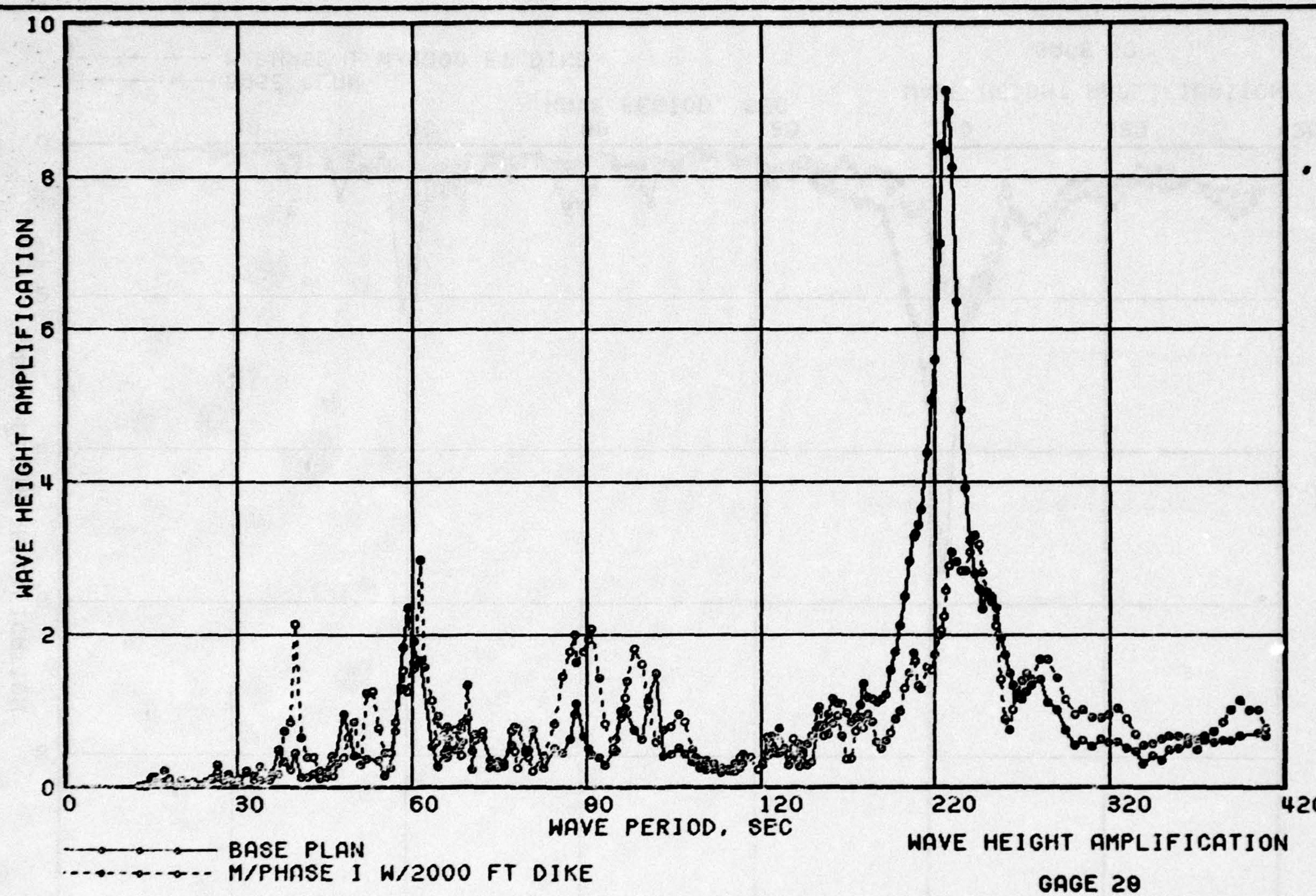
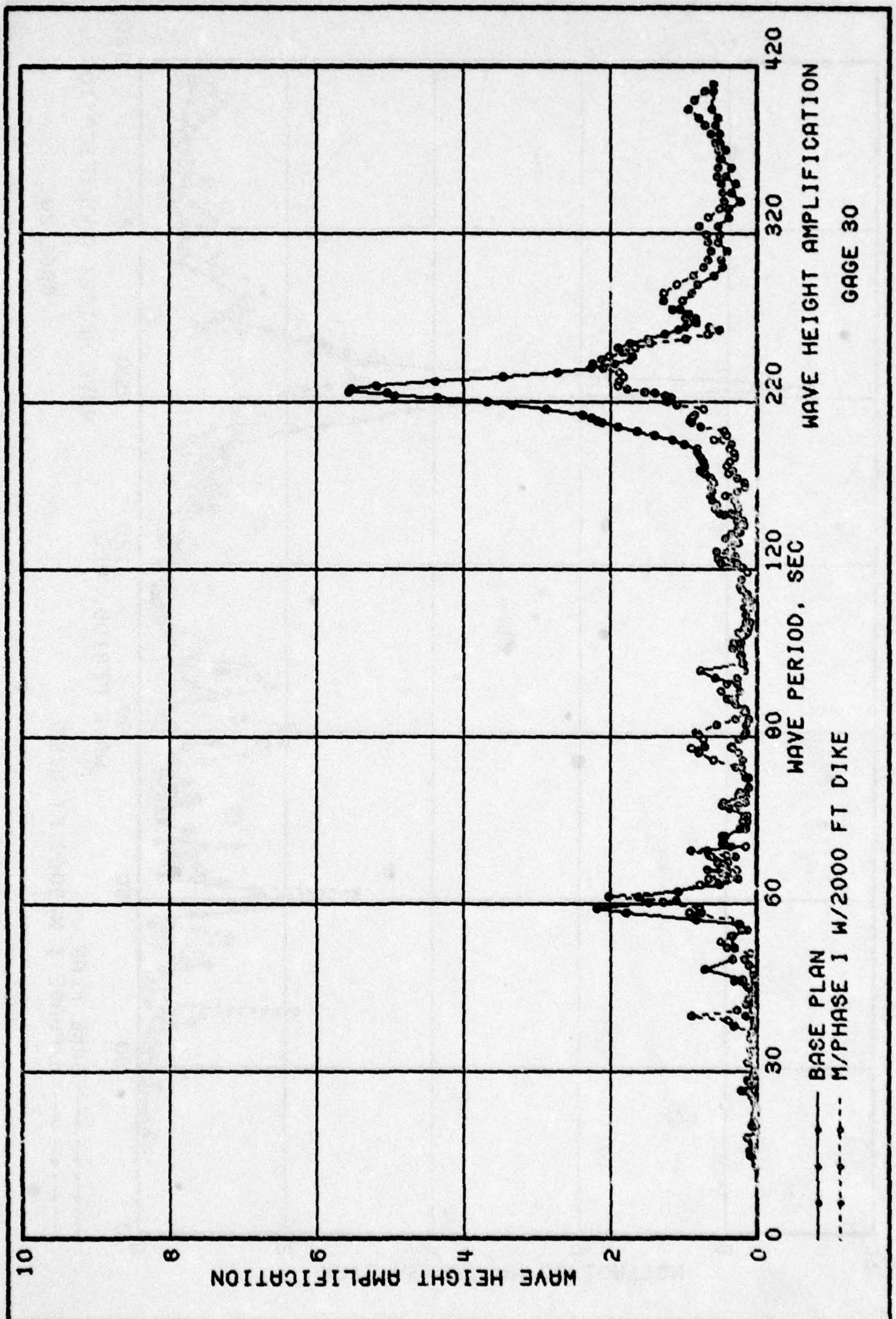

WAVE HEIGHT AMPLIFICATION
GAGE 28
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
0
30
60
90
120
220
320
420
0
1
2
3
4
5
BASE PLAN
M/PHASE I W/2000 FT DIKE

PLATE 30



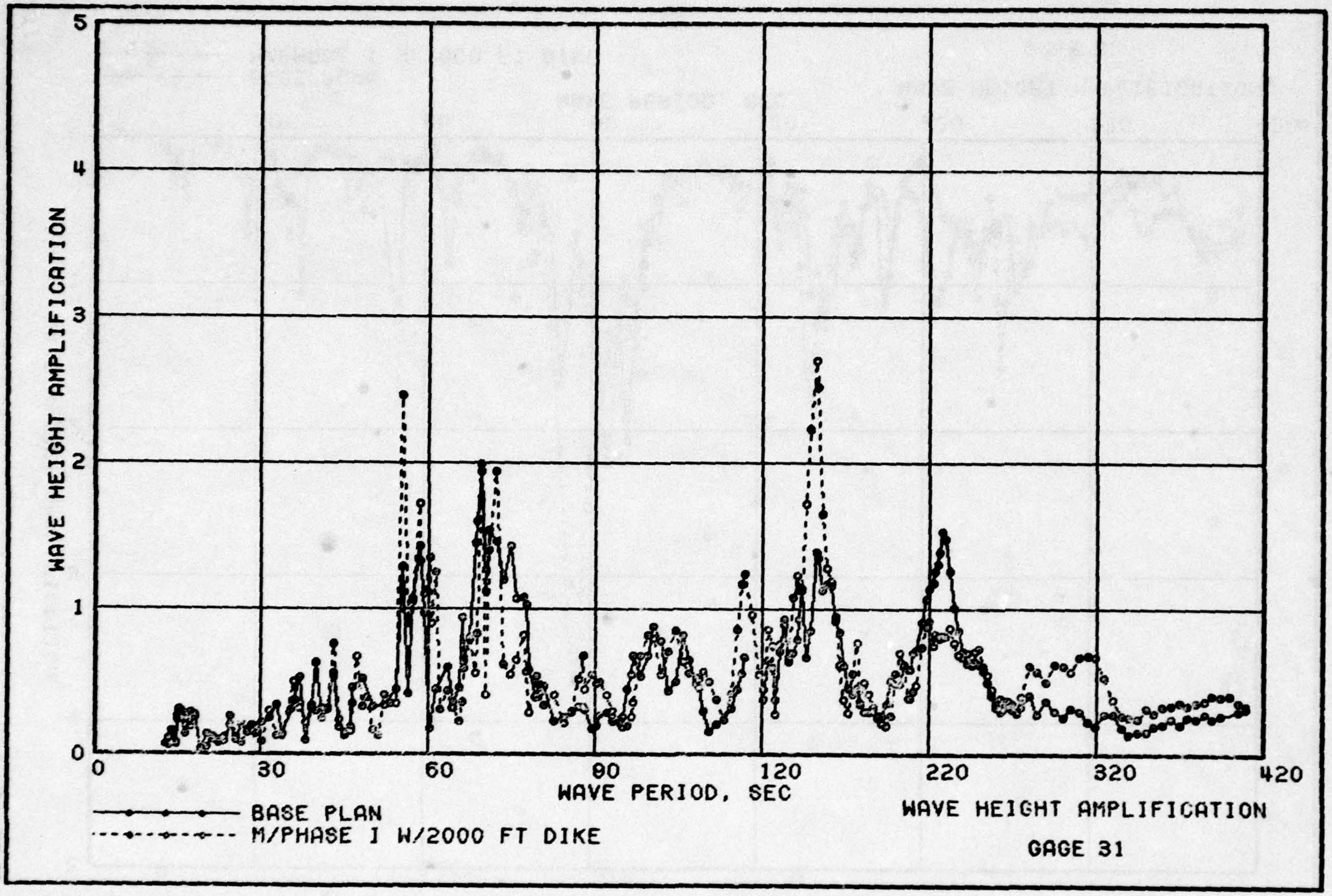
WAVE HEIGHT AMPLIFICATION

GAGE 20



WAVE HEIGHT AMPLIFICATION
0
2
4
6
8
10
WAVE PERIOD, SEC
0
30
60
90
120
220
320
420
BASE PLAN
M/PHASE I W/2000 FT DIKE
WAVE HEIGHT AMPLIFICATION
GAGE 30

PLATE 32


WAVE HEIGHT AMPLIFICATION
0
1
2
3
4
5
0
30
60
90
120
220
320
420
WAVE PERIOD, SEC
BASE PLAN
M/PHASE I W/2000 FT DIKE
WAVE HEIGHT AMPLIFICATION
GAGE 31

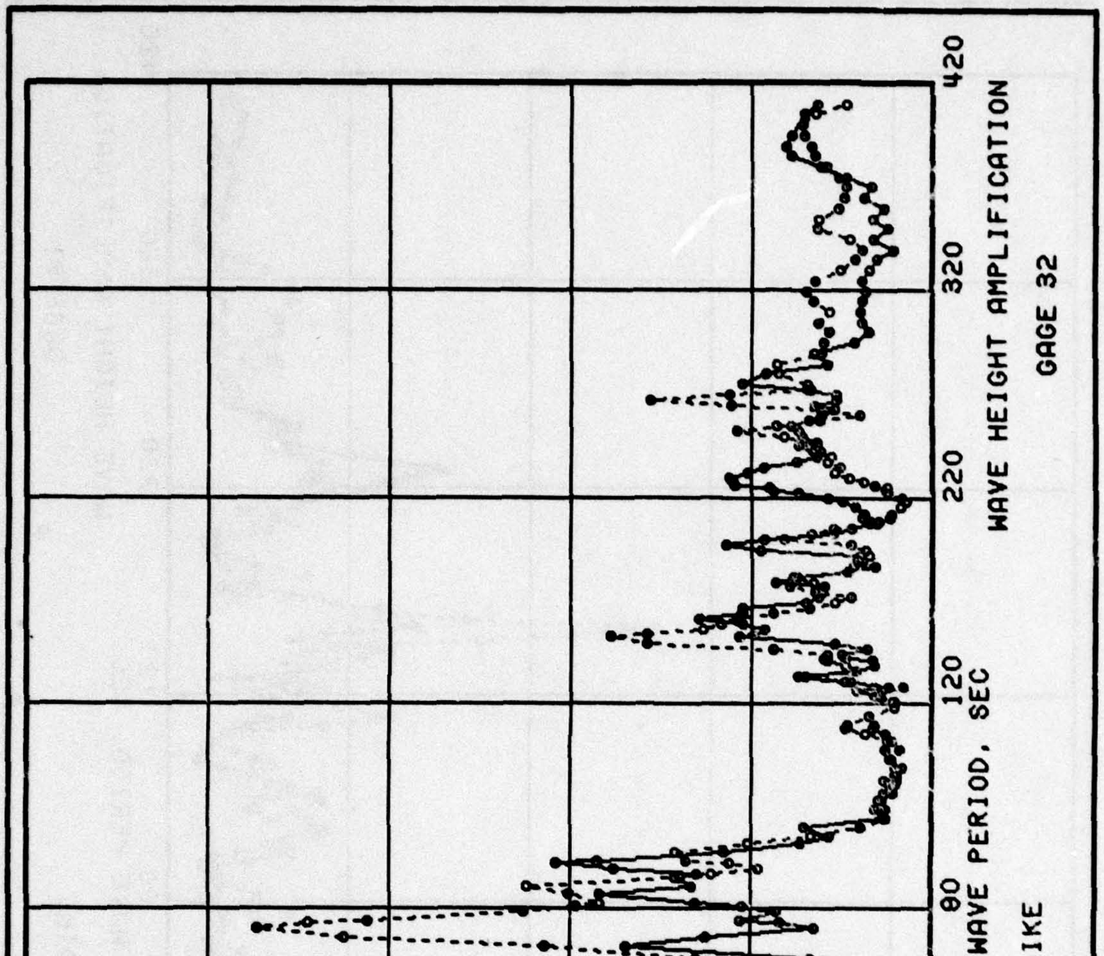
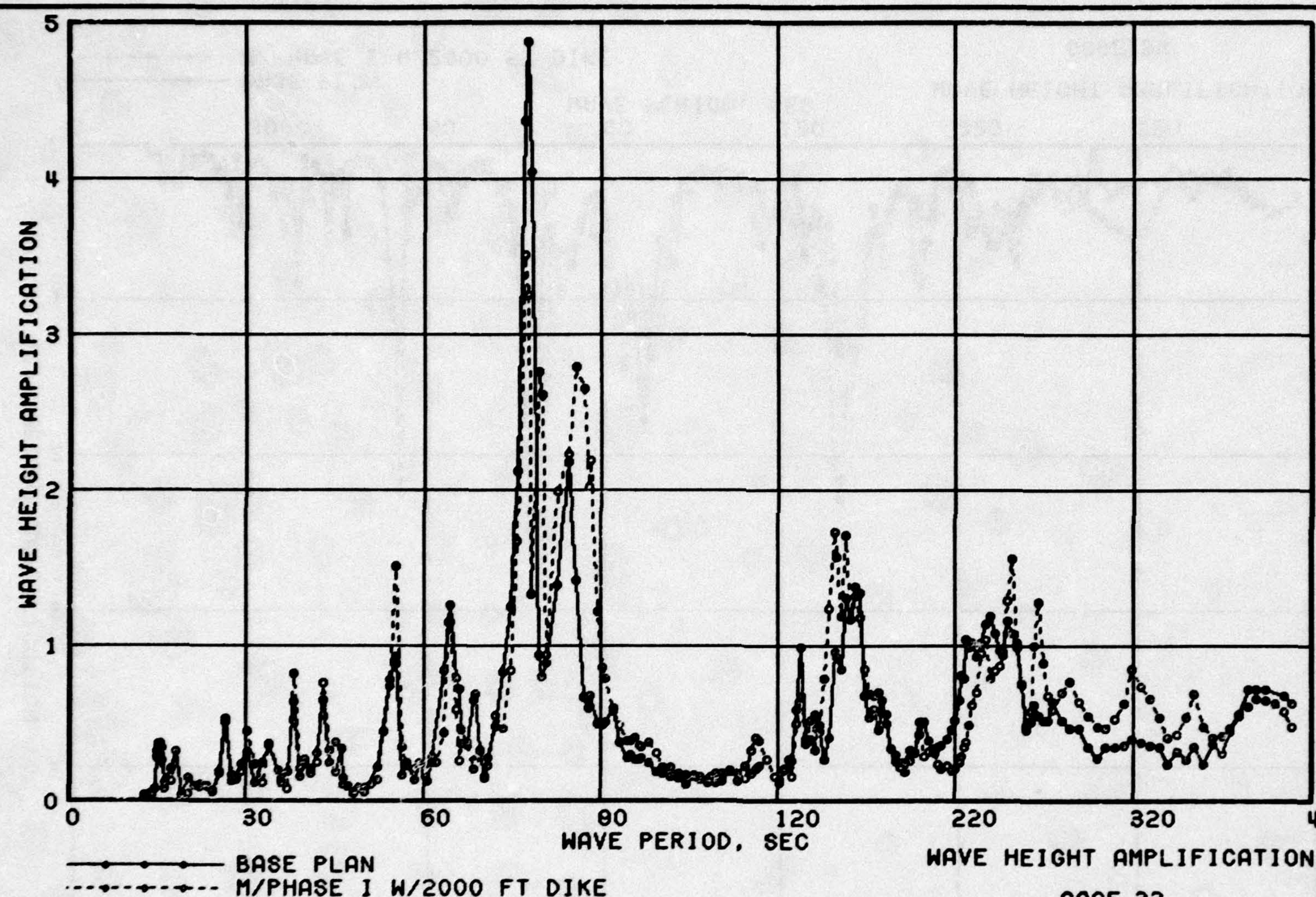

WAVE HEIGHT AMPLIFICATION
GAGE 32
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
0
1
2
3
4
5
0
30
60
90
120
220
320
420
BASE PLAN
W/PHASE I W/2000 FT DIKE

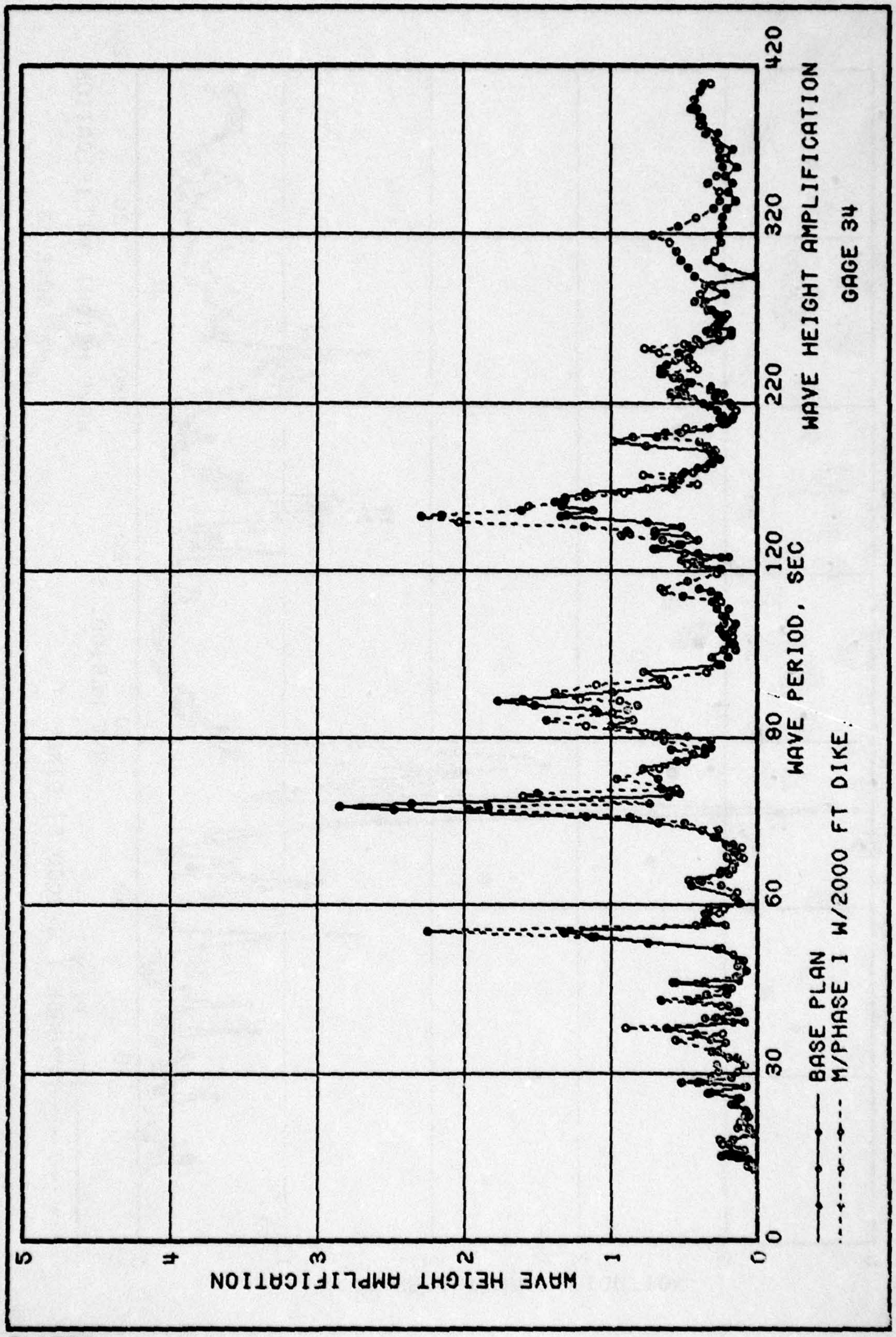
PLATE 34



WAVE HEIGHT AMPLIFICATION

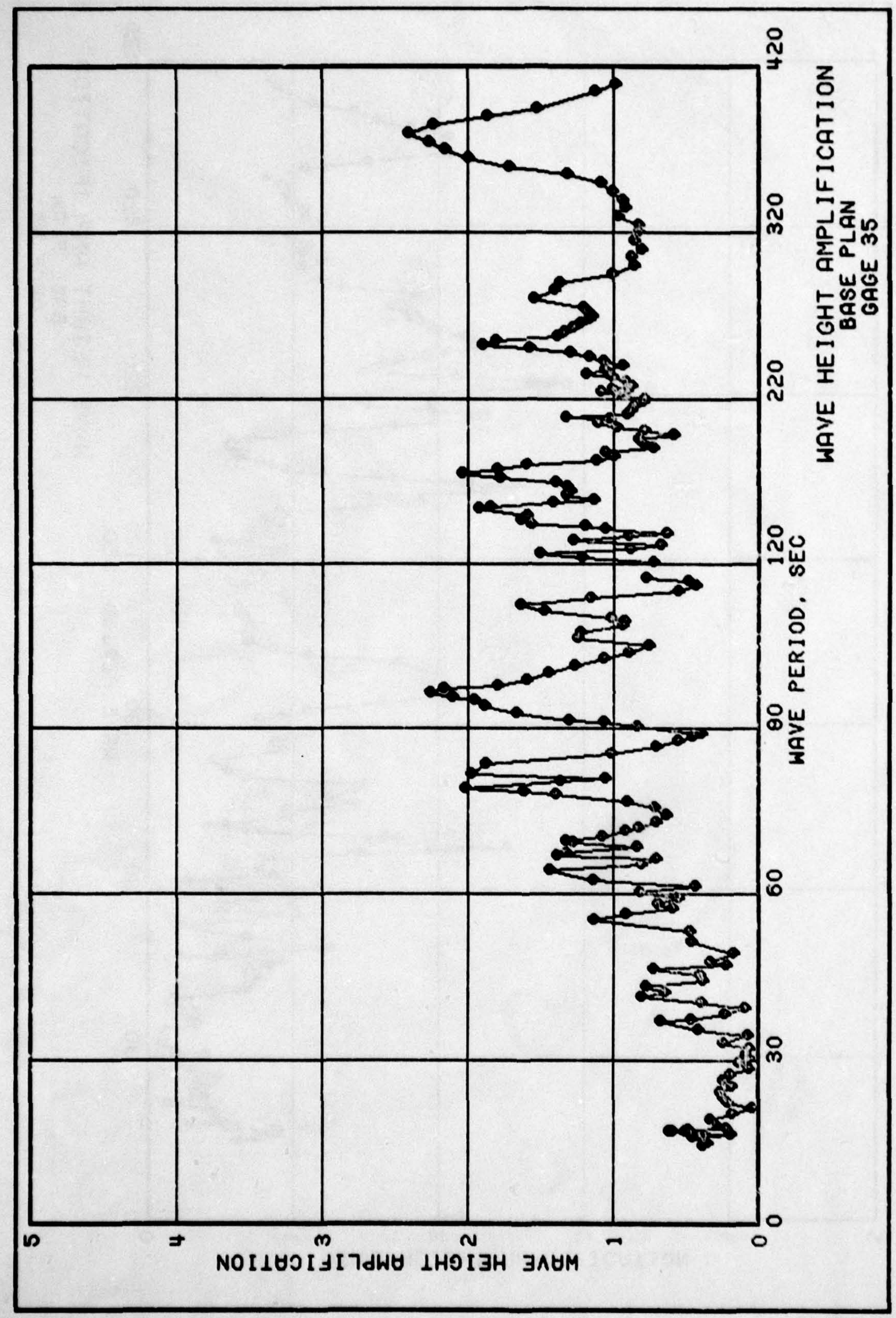
GAGE 33

PLATE 35



WAVE HEIGHT AMPLIFICATION
GAGE 34
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
BASE PLAN
M/PHASE I W/2000 FT DIKE
0
30
60
90
120
220
320
420
0
1
2
3
4
5

PLATE 36


WAVE HEIGHT AMPLIFICATION
BASE PLAN
GAGE 35
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
0
1
2
3
4
5
0
30
60
90
120
220
320
420

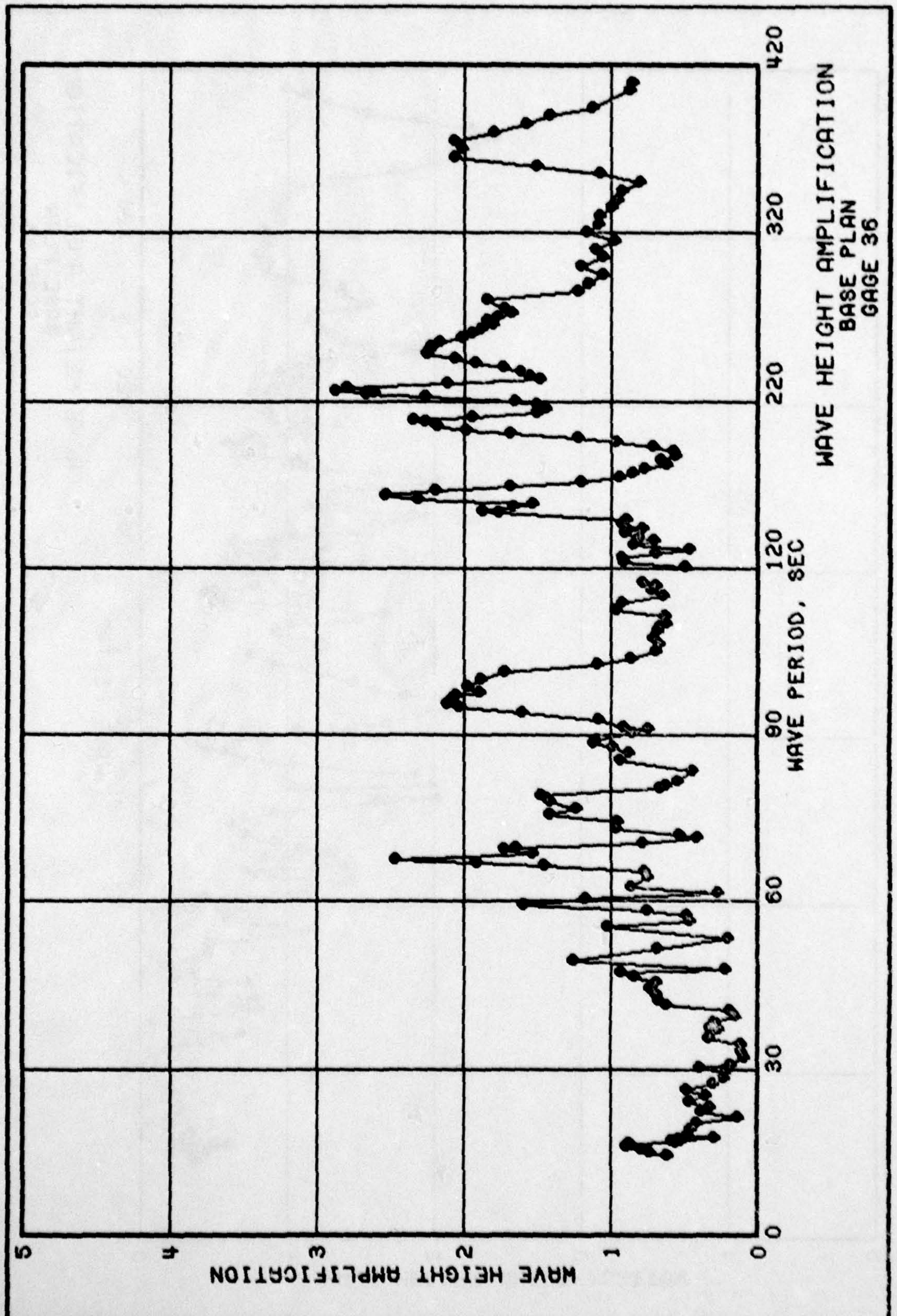
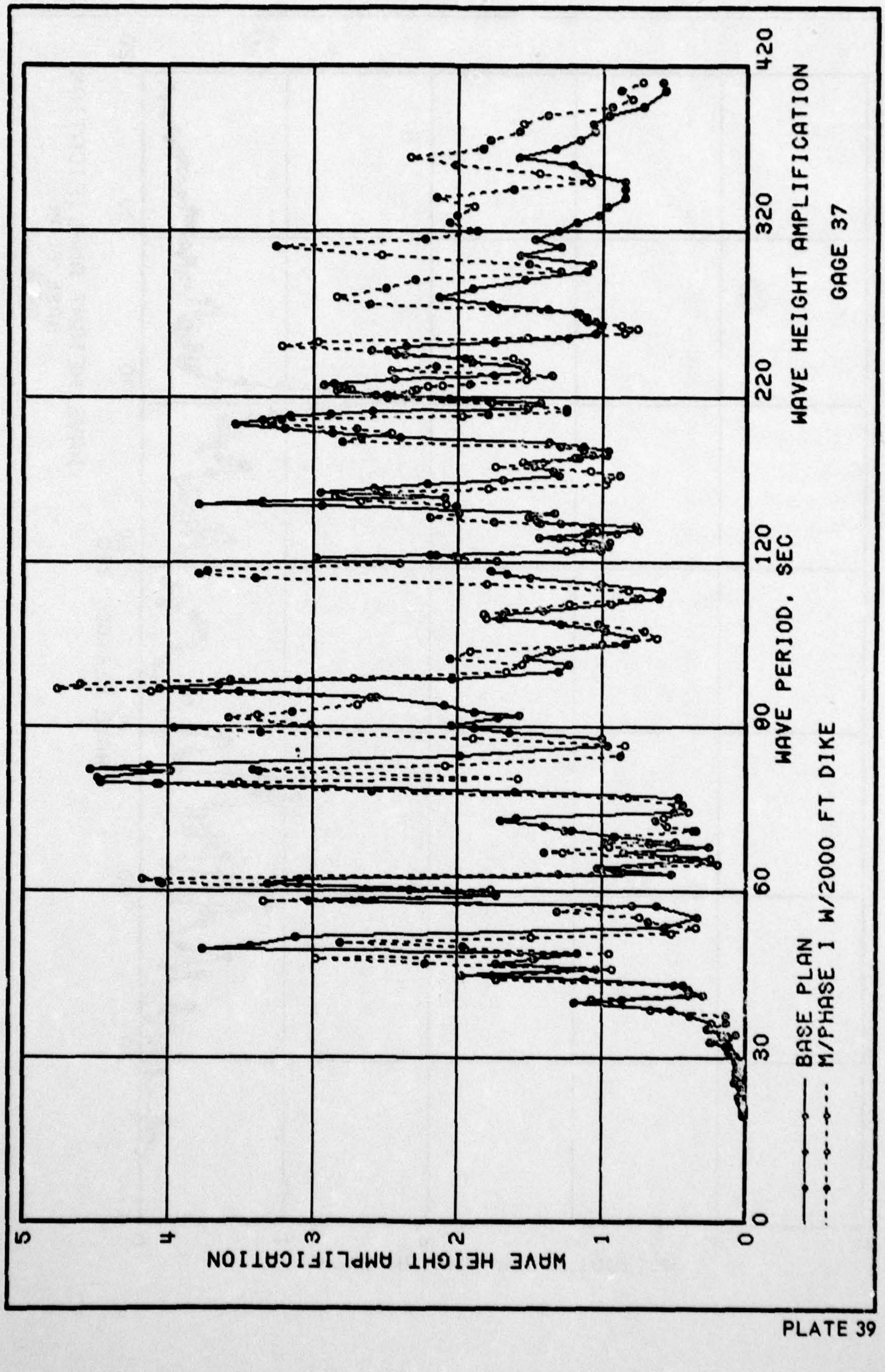

WAVE HEIGHT AMPLIFICATION
BASE PLAN
GAGE 36
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
0
30
60
90
120
220
320
420
0
1
2
3
4
5

PLATE 38


WAVE HEIGHT AMPLIFICATION
WAVE PERIOD, SEC
0
30
60
90
120
220
320
420
1
2
3
4
5
BASE PLAN
M/PHASE I W/2000 FT DIKE
WAVE HEIGHT AMPLIFICATION
GAGE 37

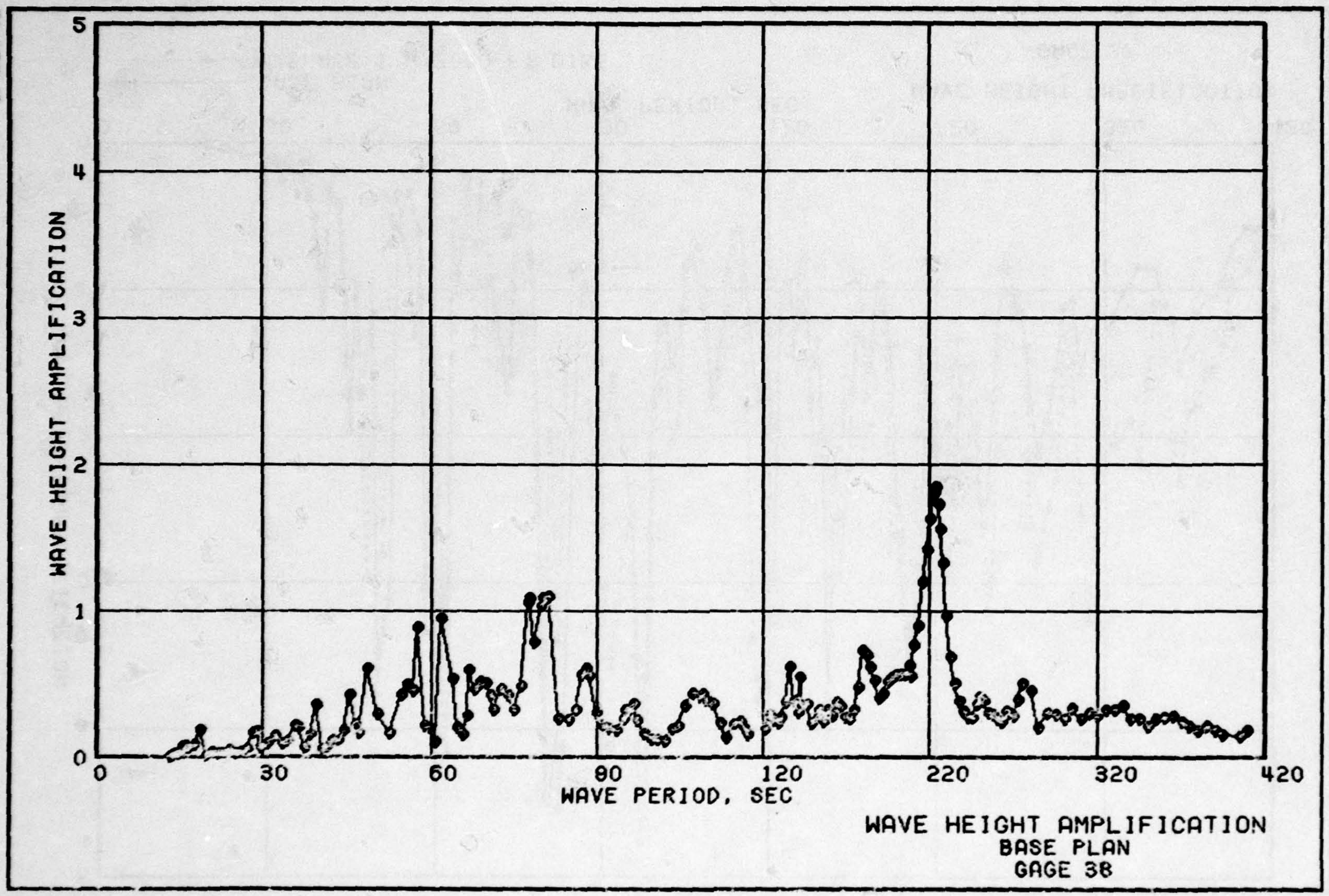
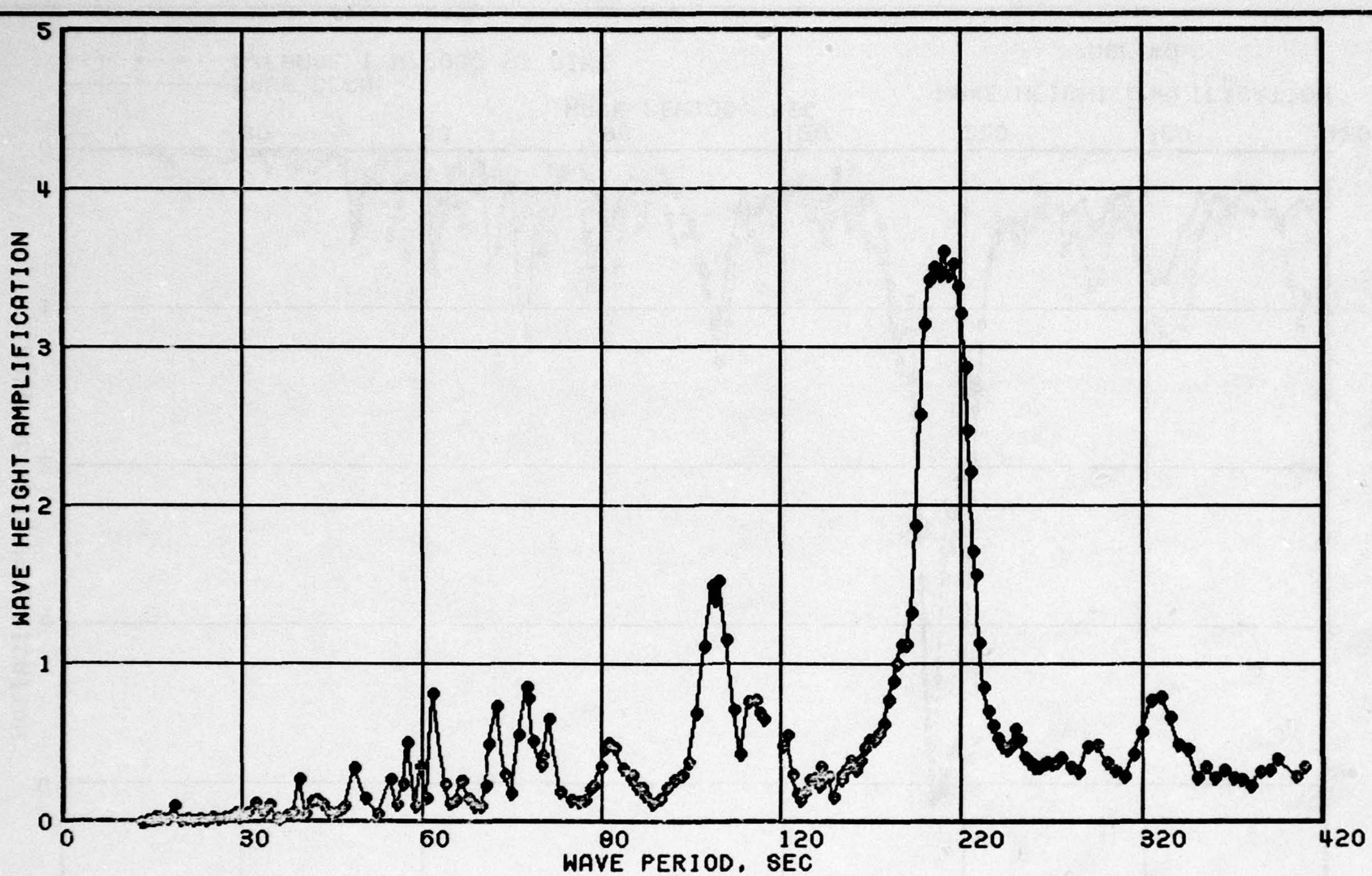
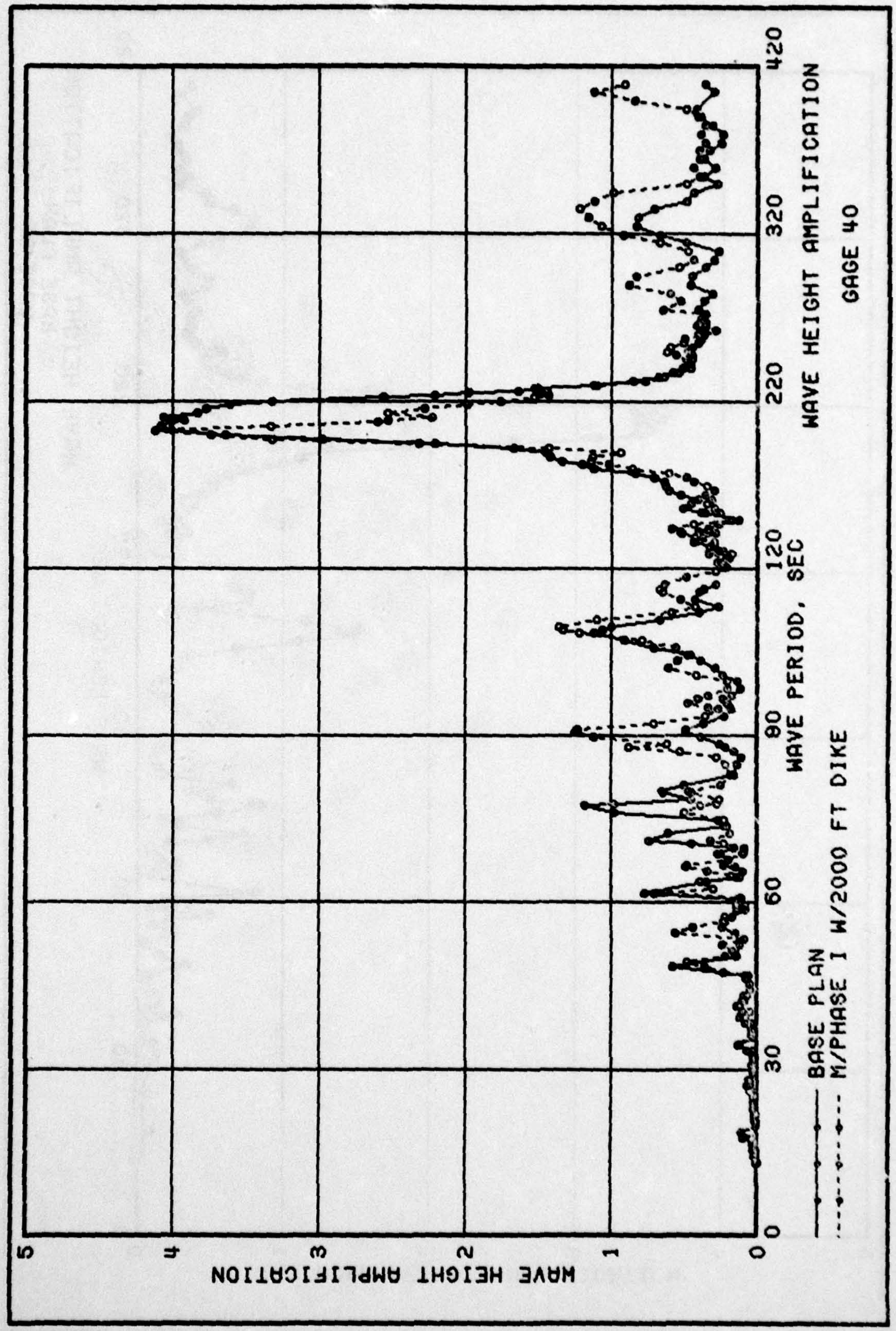

WAVE HEIGHT AMPLIFICATION
0
1
2
3
4
5
0
30
60
90
120
220
320
420
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
BASE PLAN
GAGE 38

PLATE 40



WAVE HEIGHT AMPLIFICATION
BASE PLAN
GAGE 39



WAVE HEIGHT AMPLIFICATION
GAGE 40
WAVE HEIGHT AMPLIFICATION
WAVE PERIOD, SEC
0
30
60
90
120
220
320
420
0
1
2
3
4
5
BASE PLAN
M/PHASE I W/2000 FT DIKE

PLATE 42

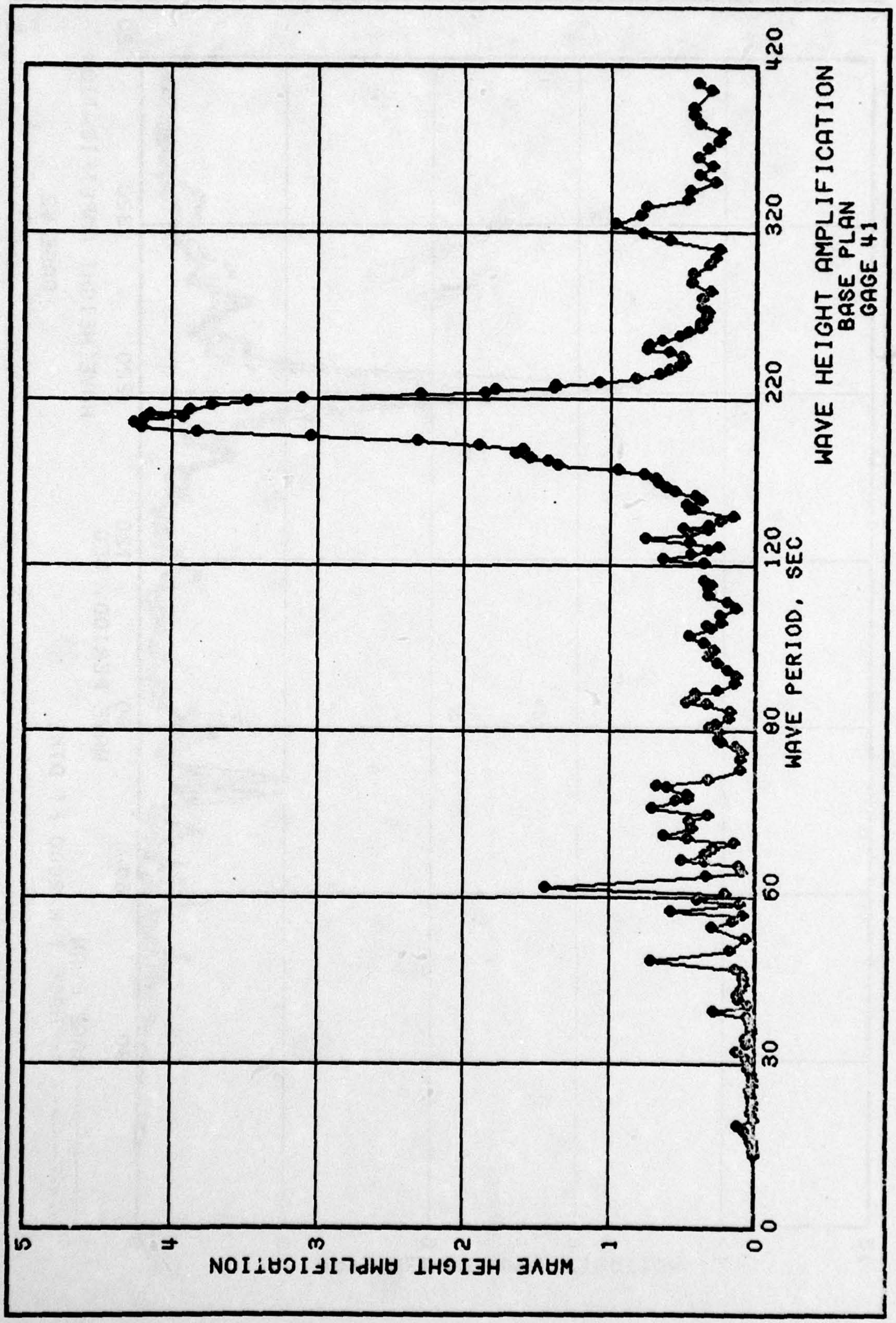
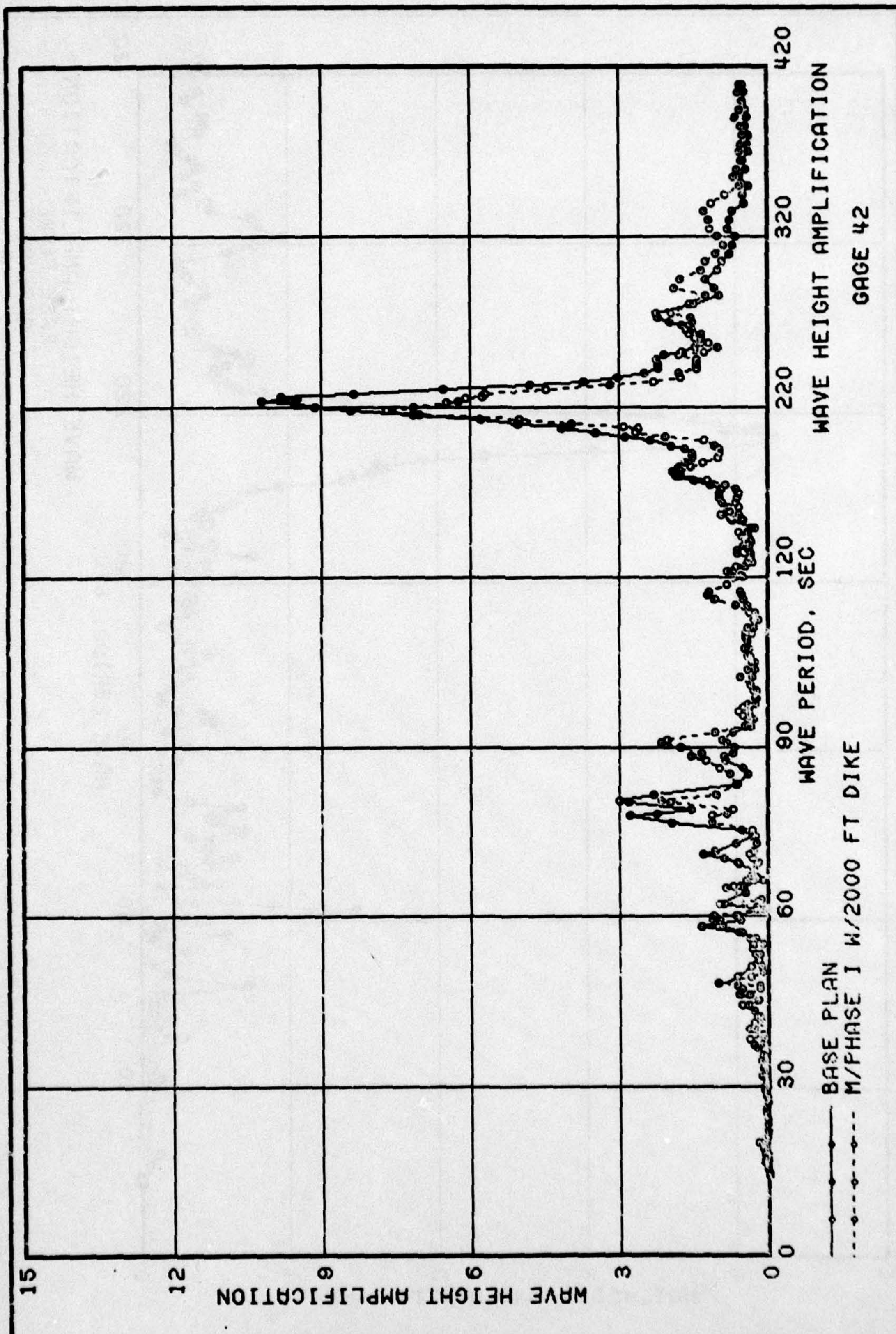
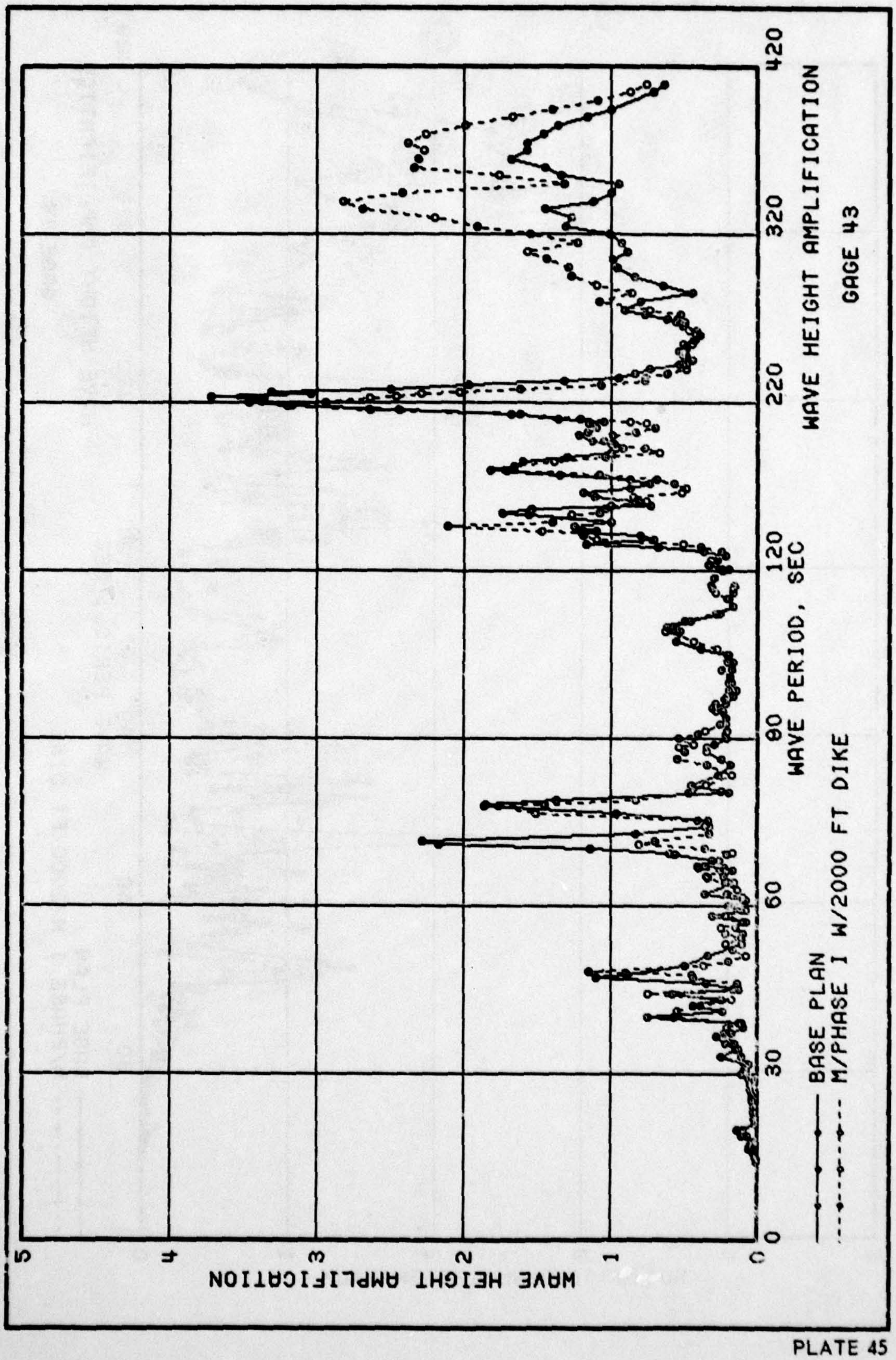
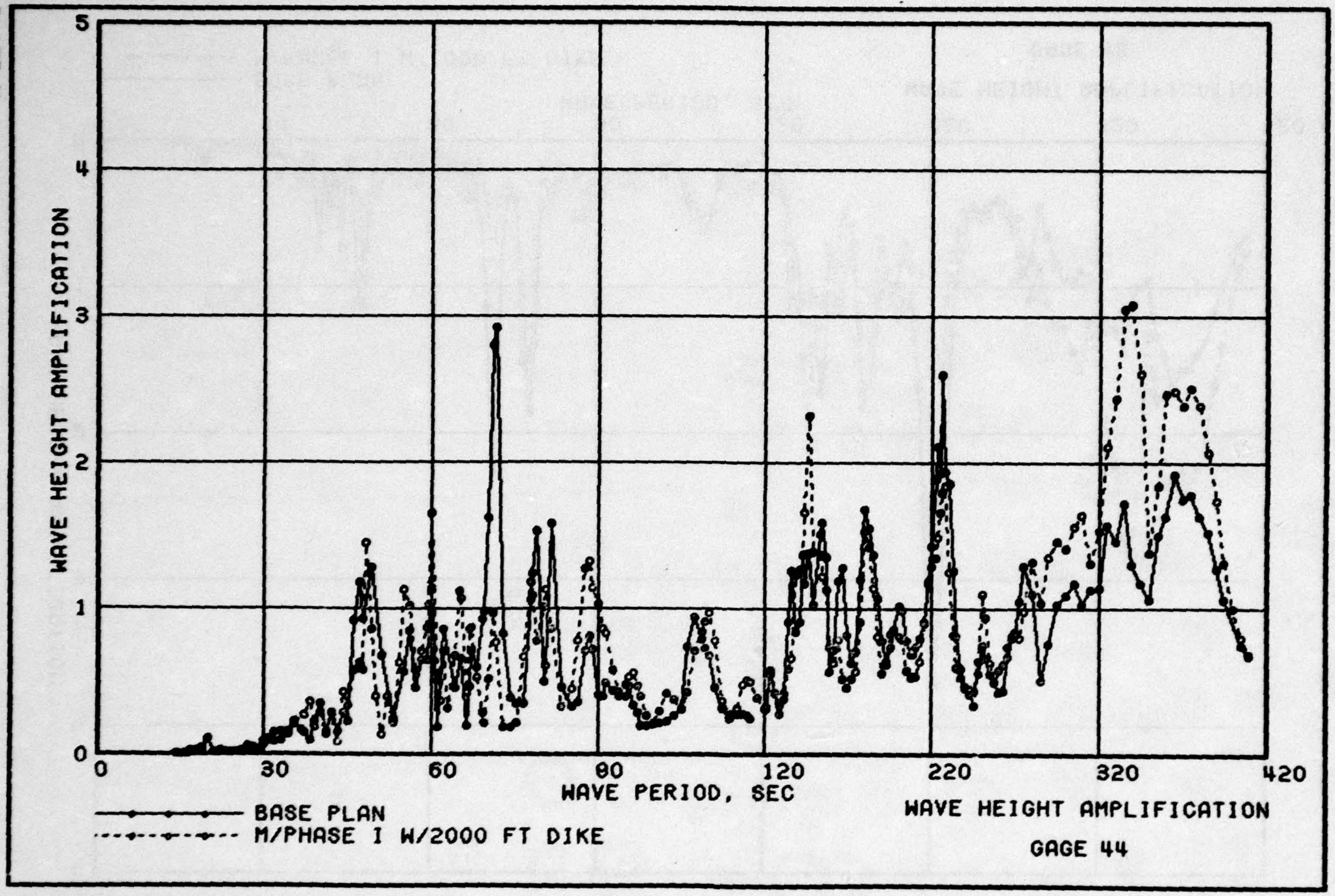

WAVE HEIGHT AMPLIFICATION
0
1
2
3
4
5
WAVE PERIOD, SEC
0
30
60
80
120
220
320
420
WAVE HEIGHT AMPLIFICATION
BASE PLAN
GAGE 41

PLATE 43


WAVE HEIGHT AMPLIFICATION
GAGE 42
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
0
30
60
90
120
220
320
420
0
3
6
9
12
15
BASE PLAN
M/PHASE I W/2000 FT DIKE

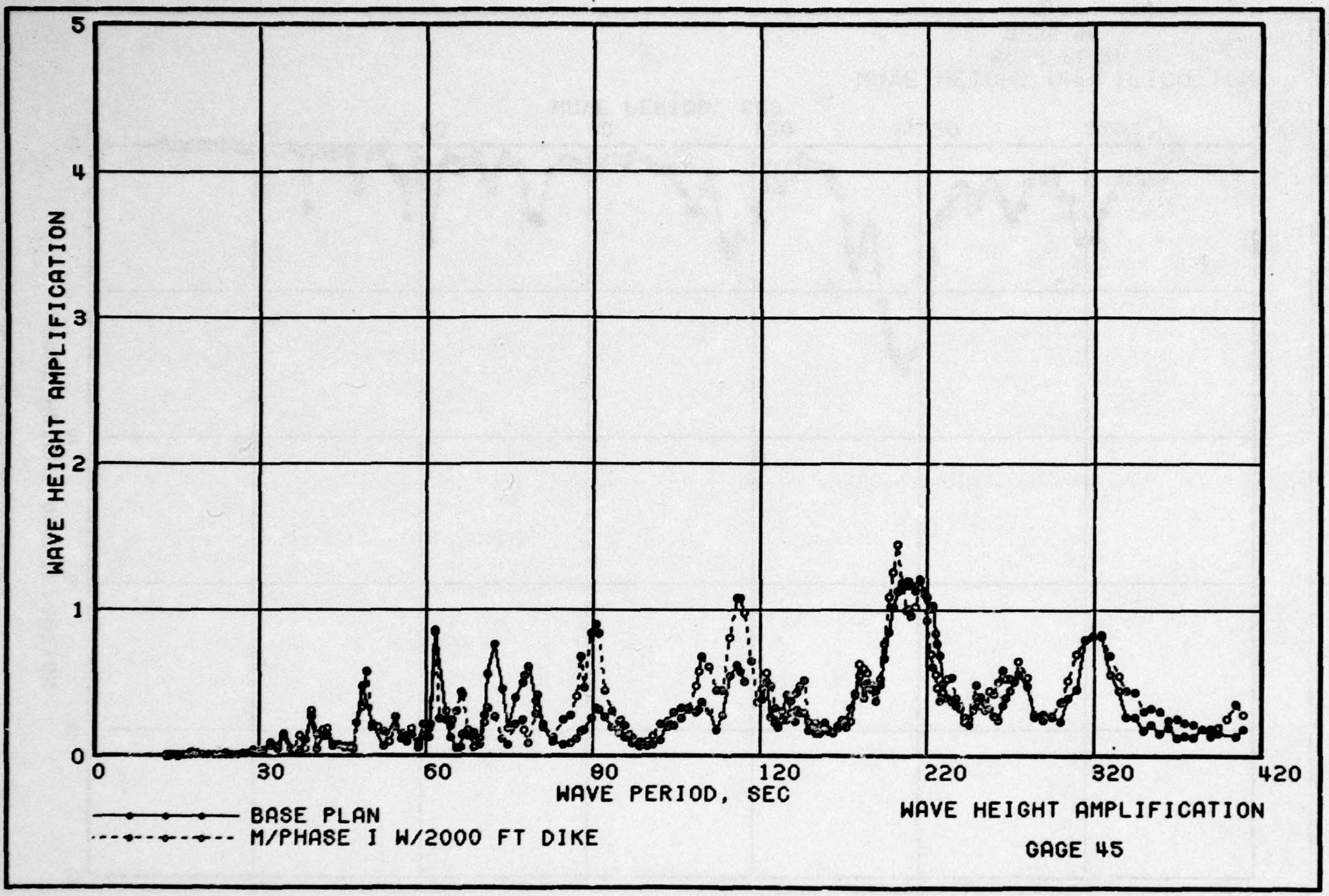


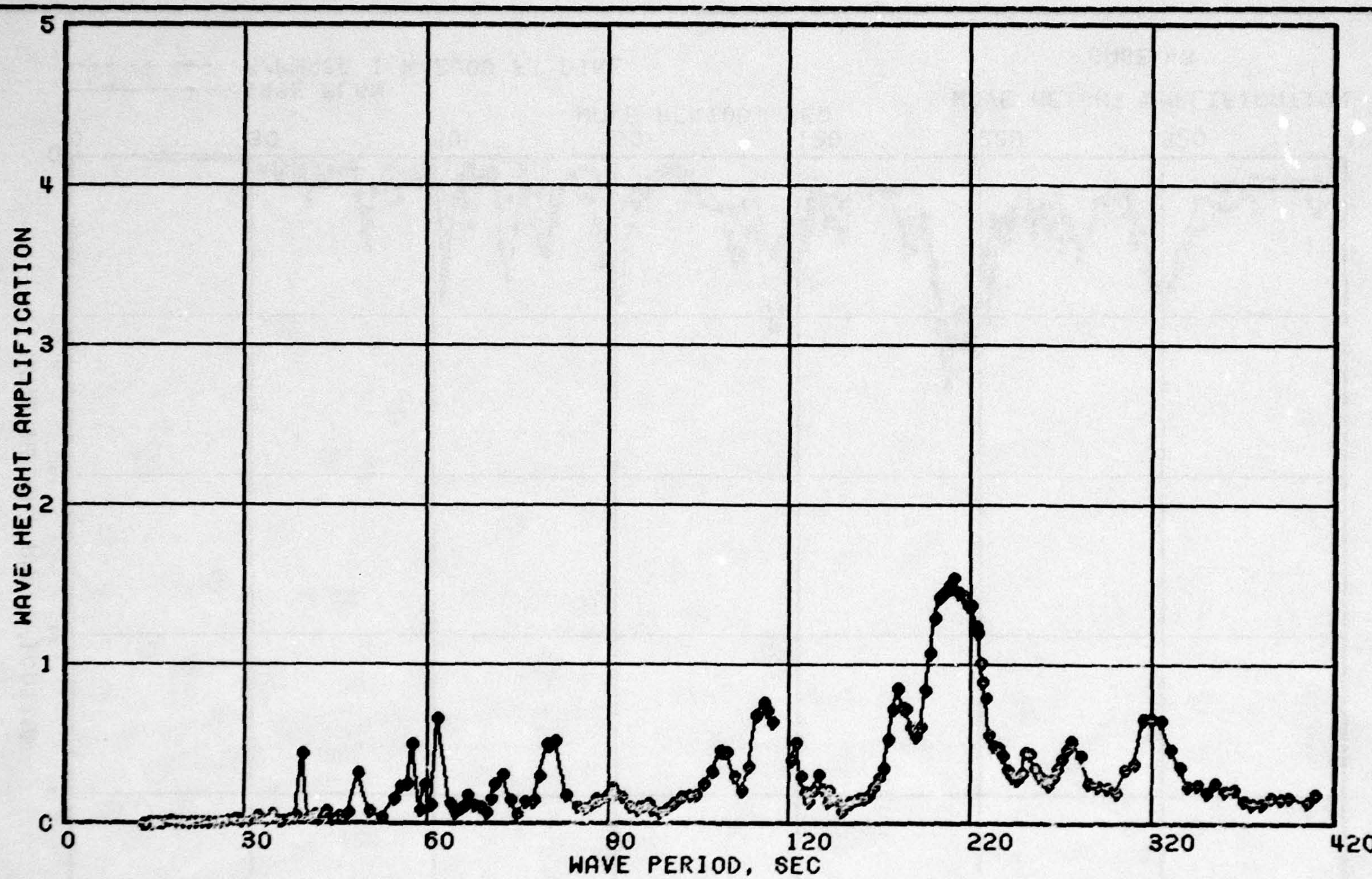
WAVE HEIGHT AMPLIFICATION
GAGE 43
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
0
30
60
90
120
220
320
420
0
1
2
3
4
5
BASE PLAN
M/PHASE I W/2000 FT DIKE



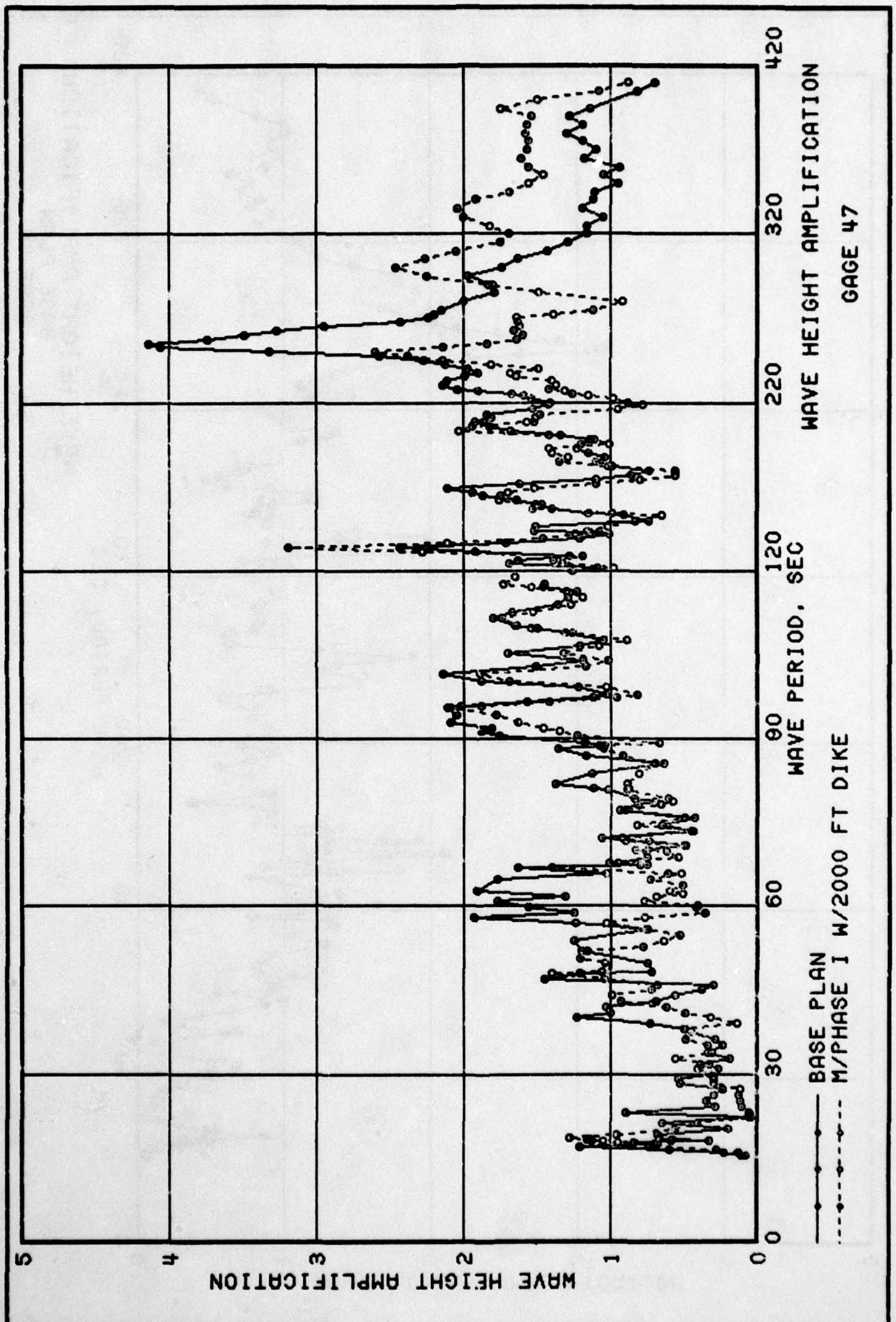
WAVE HEIGHT AMPLIFICATION
0
1
2
3
4
5
0
30
60
90
120
220
320
420
WAVE PERIOD, SEC
BASE PLAN
M/PHASE I W/2000 FT DIKE
WAVE HEIGHT AMPLIFICATION
GAGE 44

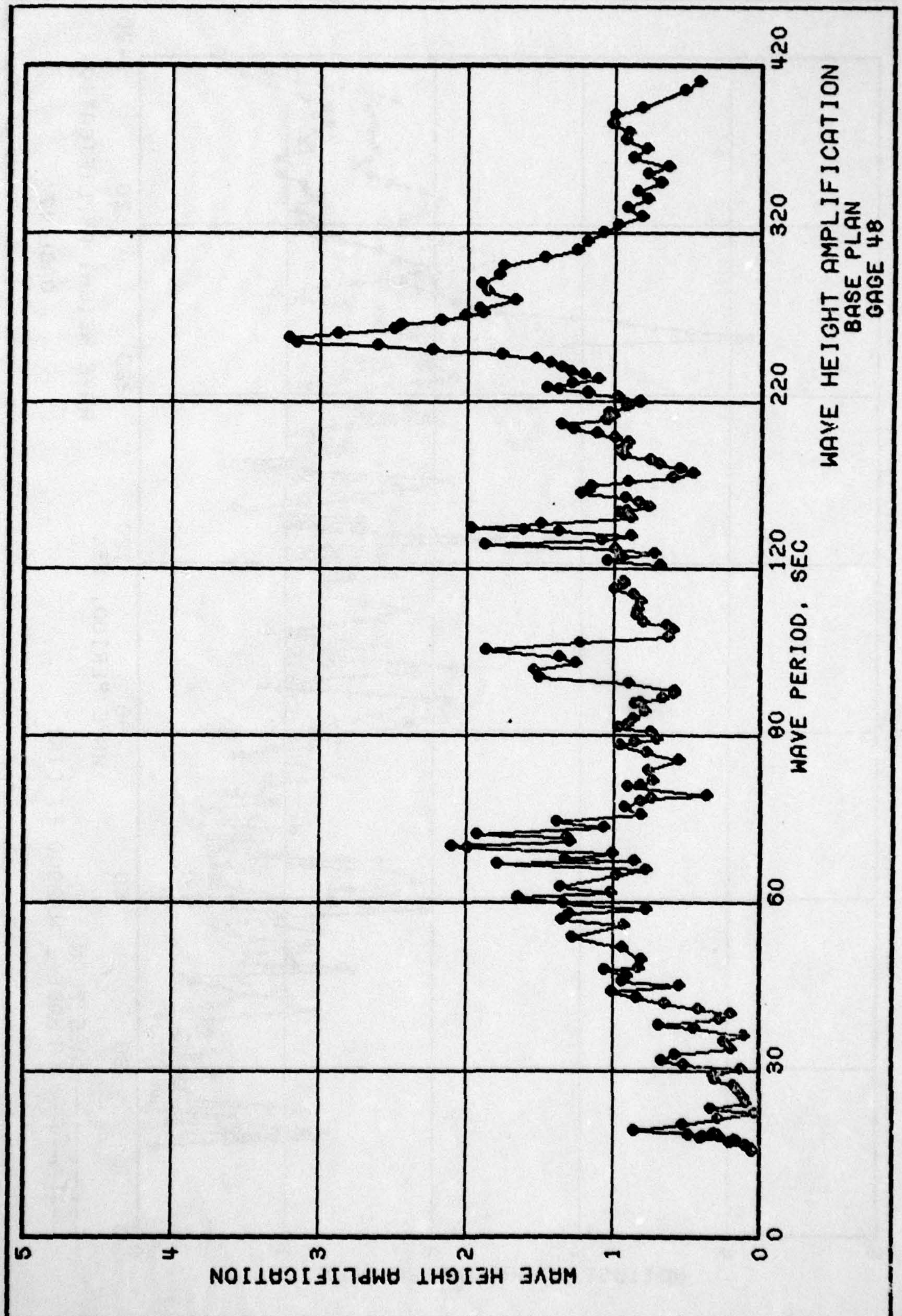
PLATE 46


WAVE HEIGHT AMPLIFICATION
5
4
3
2
1
0
0
30
60
90
120
220
320
420
WAVE PERIOD, SEC
BASE PLAN
M/PHASE I W/2000 FT DIKE
WAVE HEIGHT AMPLIFICATION
GAGE 45



WAVE HEIGHT AMPLIFICATION
BASE PLAN
GAGE 46


WAVE HEIGHT AMPLIFICATION
GAGE 47
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
BASE PLAN
M/PHASE I W/2000 FT DIKE
0
30
60
90
120
220
320
420
0
1
2
3
4
5


WAVE HEIGHT AMPLIFICATION
BASE PLAN
GAGE 48
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
0
30
60
90
120
220
320
420
0
1
2
3
4
5

AD-A075 728 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 13/13
LOS ANGELES AND LONG BEACH HARBORS MODEL STUDY: REPORT 6. RESON--ETC(U)
AUG 79 D G OUTLAW
UNCLASSIFIED WES-HL-75-4-6 NL

2 OF 2
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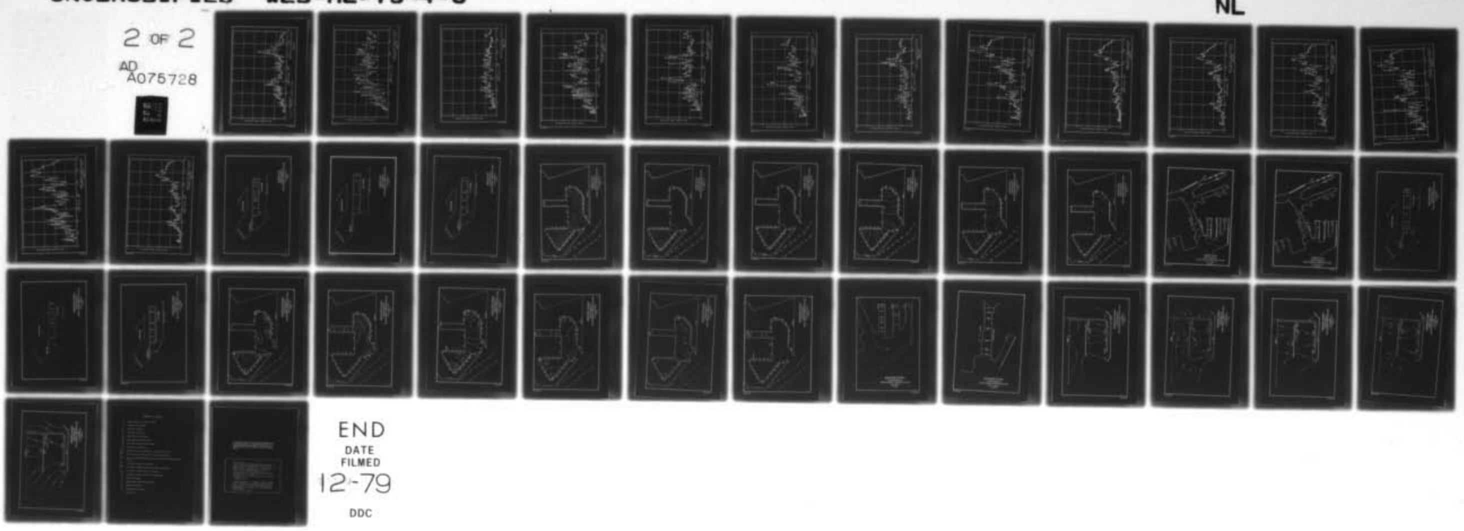

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DATE
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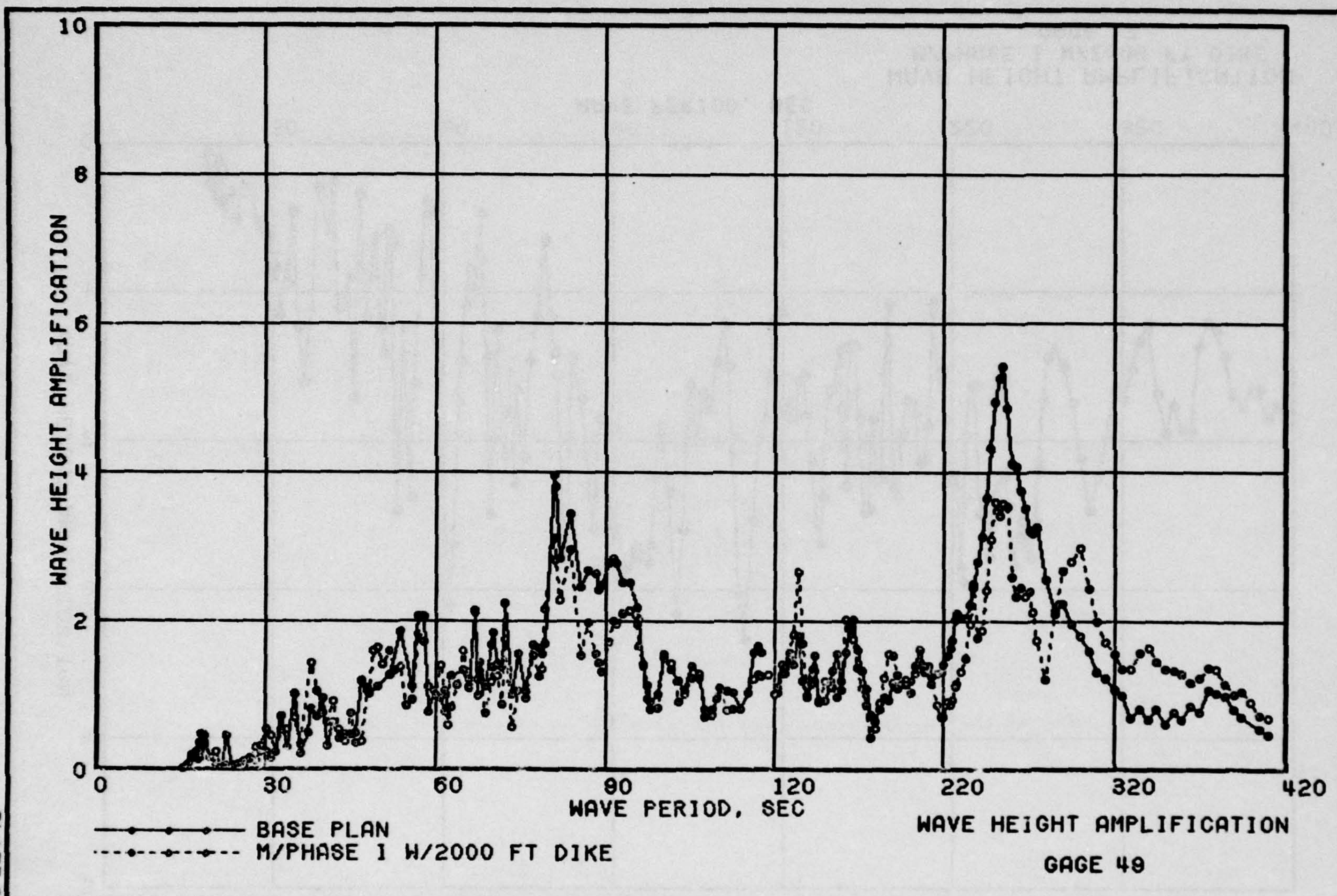
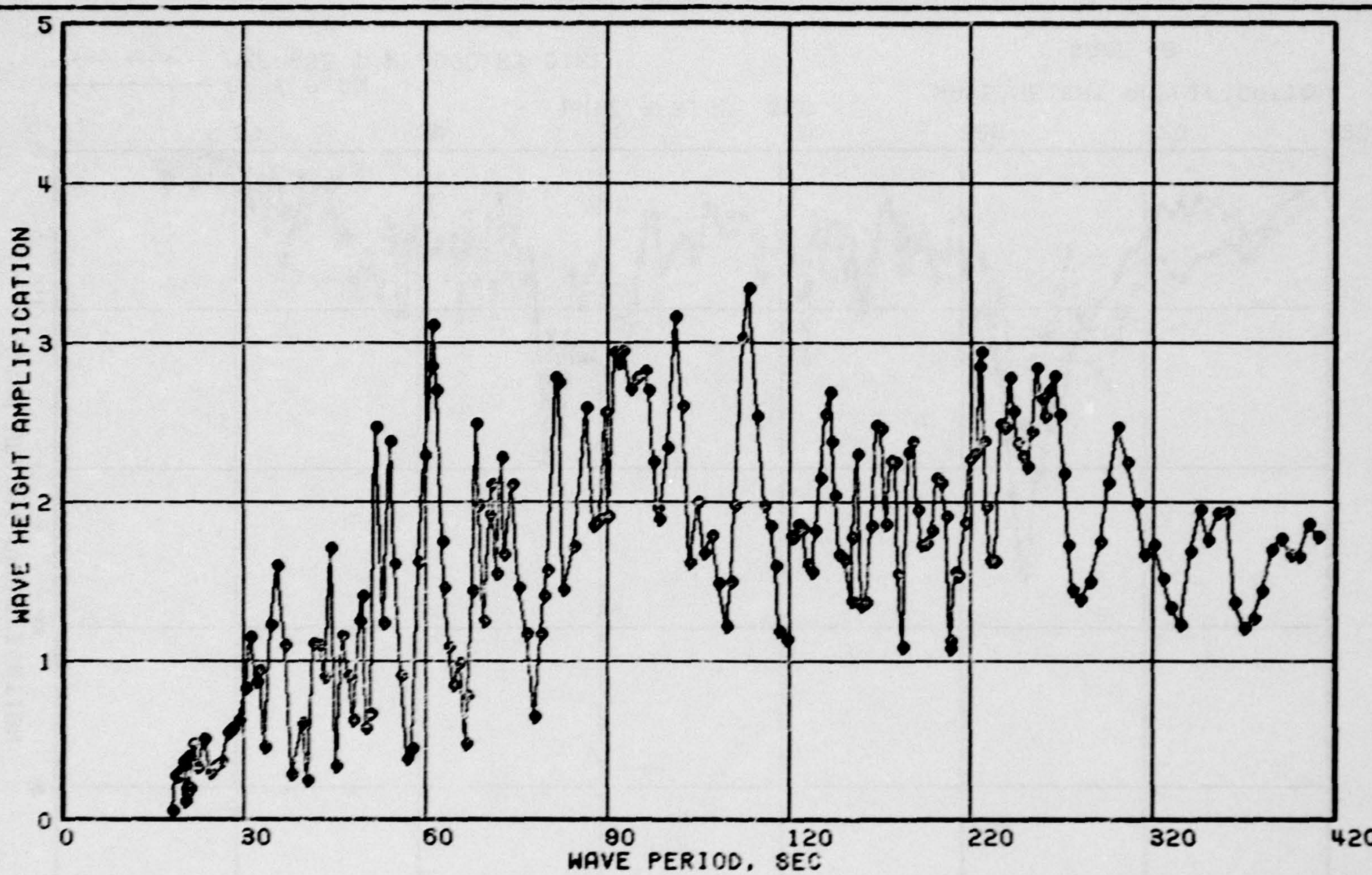
12-79
DDC

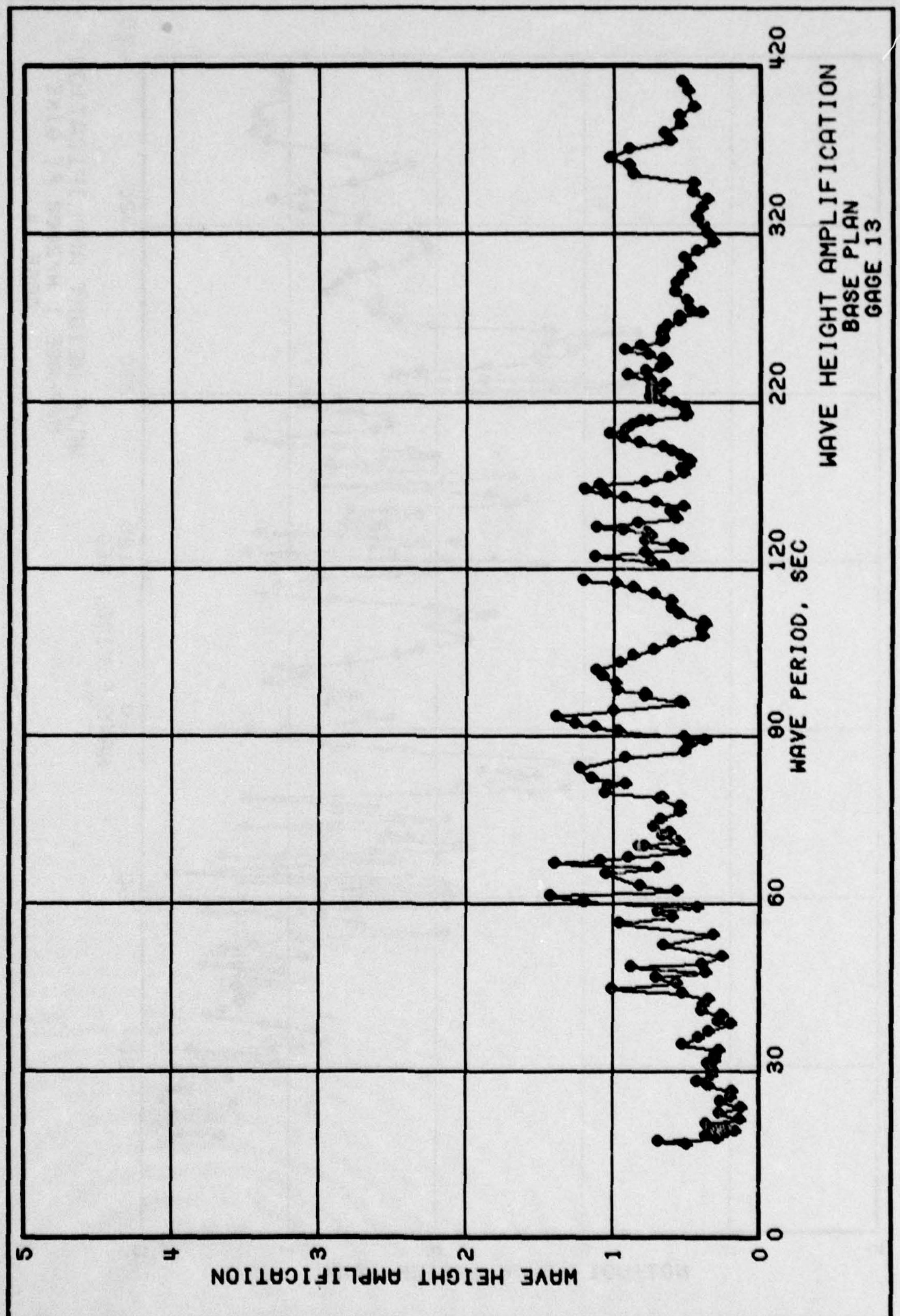


WAVE HEIGHT AMPLIFICATION

GAGE 49



WAVE HEIGHT AMPLIFICATION
M/PHASE I W/2000 FT DIKE
GAGE 12


WAVE HEIGHT AMPLIFICATION
BASE PLAN
GAGE 13
WAVE PERIOD, SEC
0
30
60
90
120
220
320
420
WAVE HEIGHT AMPLIFICATION
0
1
2
3
4
5

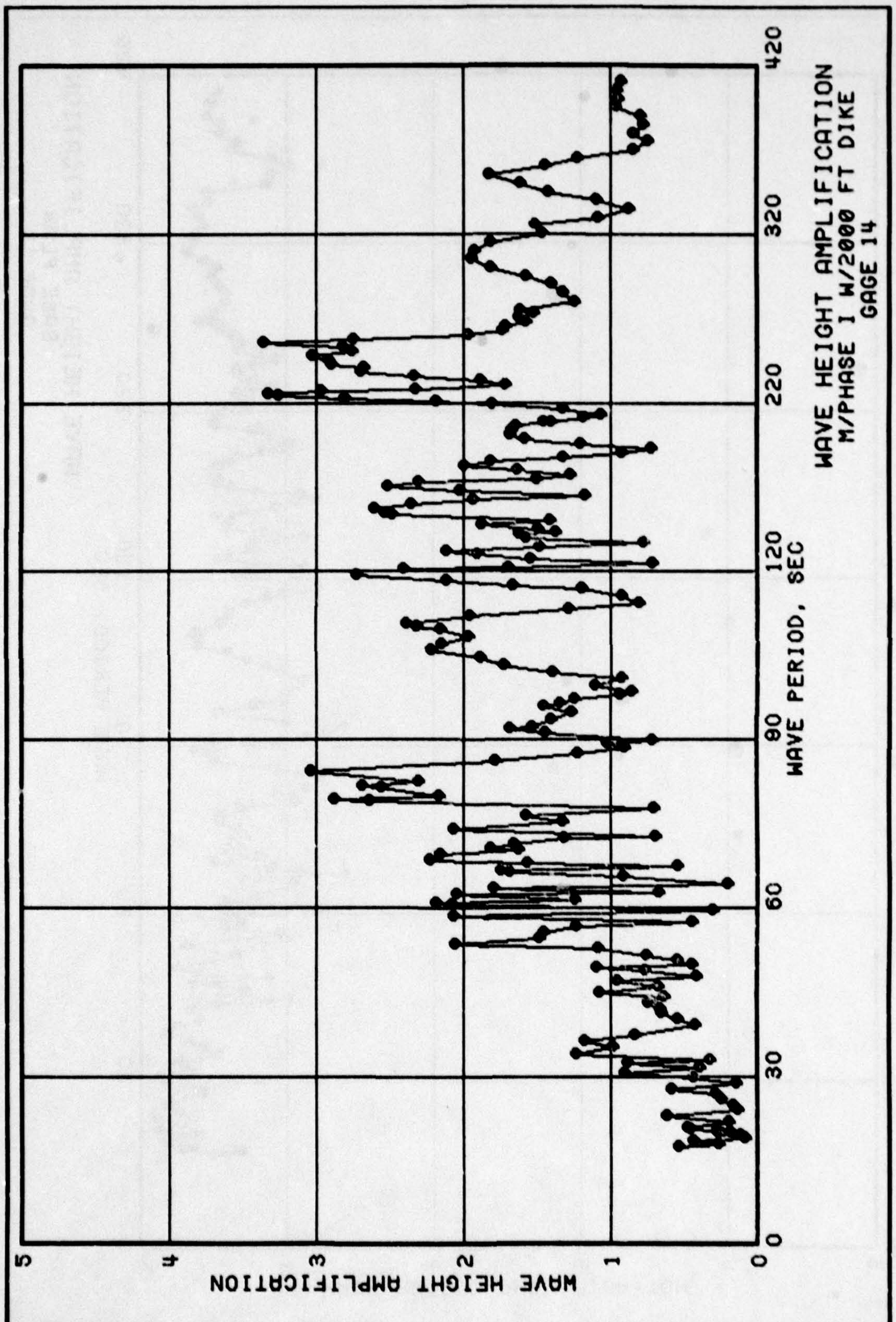
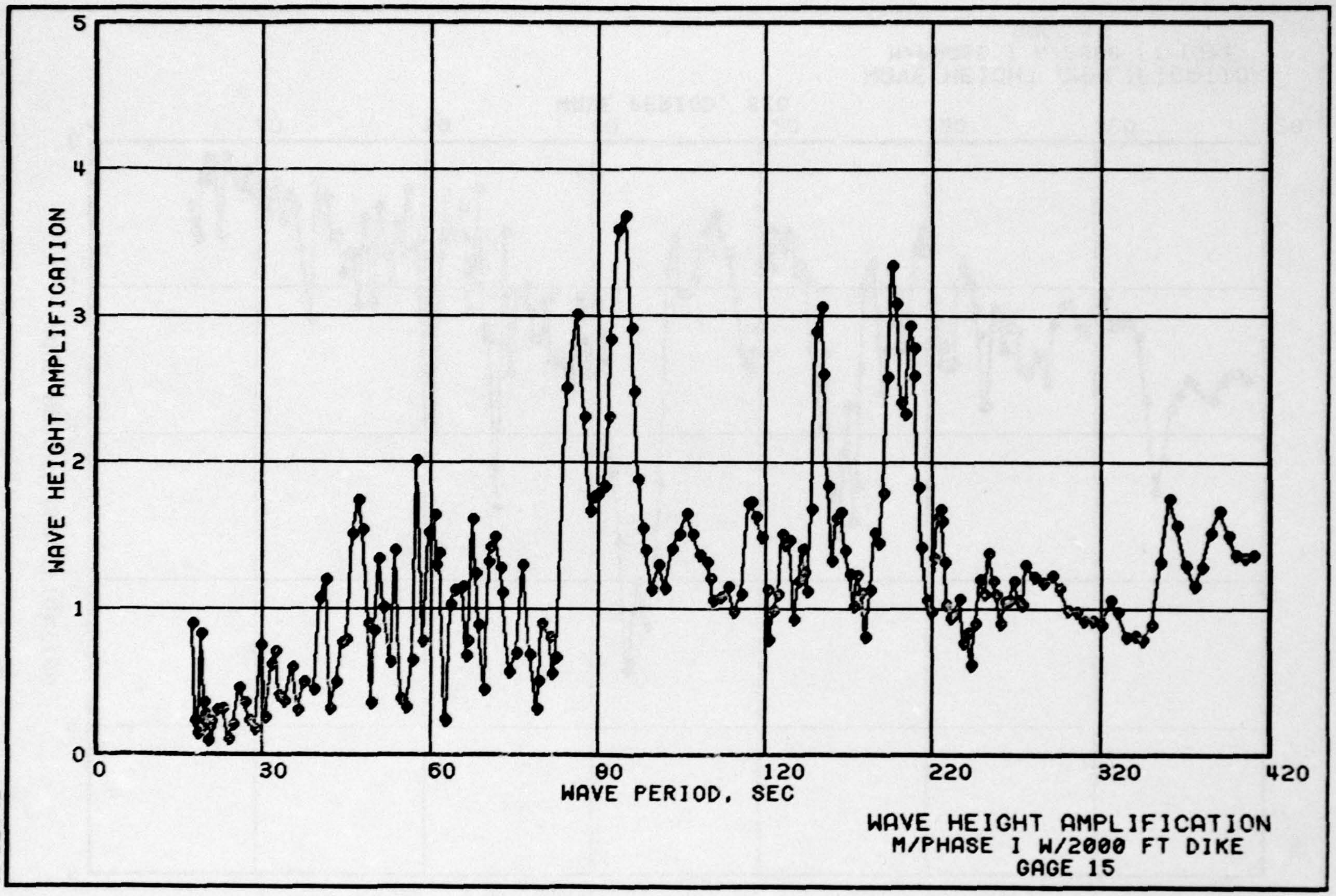
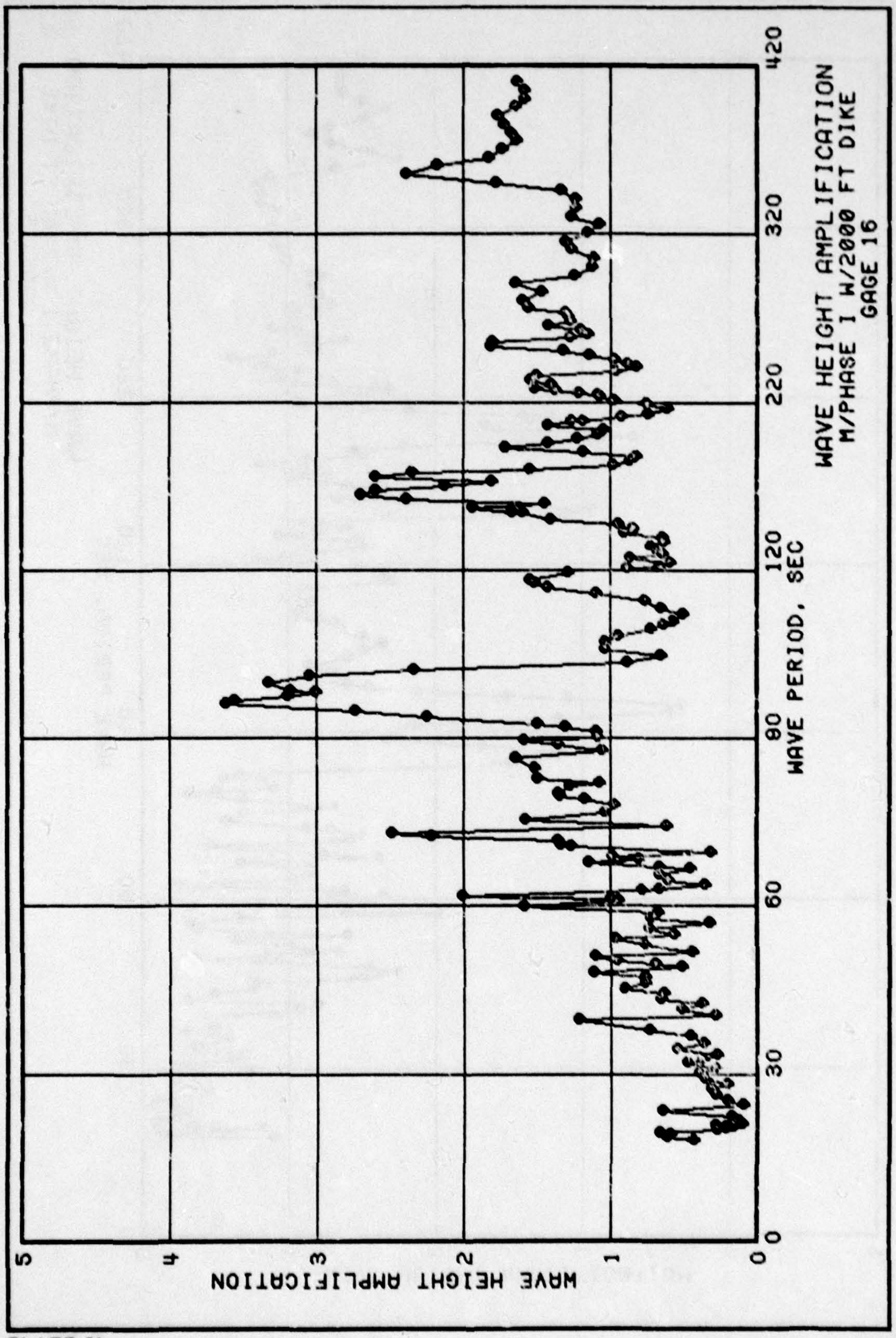

WAVE HEIGHT AMPLIFICATION
M/PHASE I W/2000 FT DIKE
GAGE 14
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
0
30
60
90
120
220
320
420
0
1
2
3
4
5

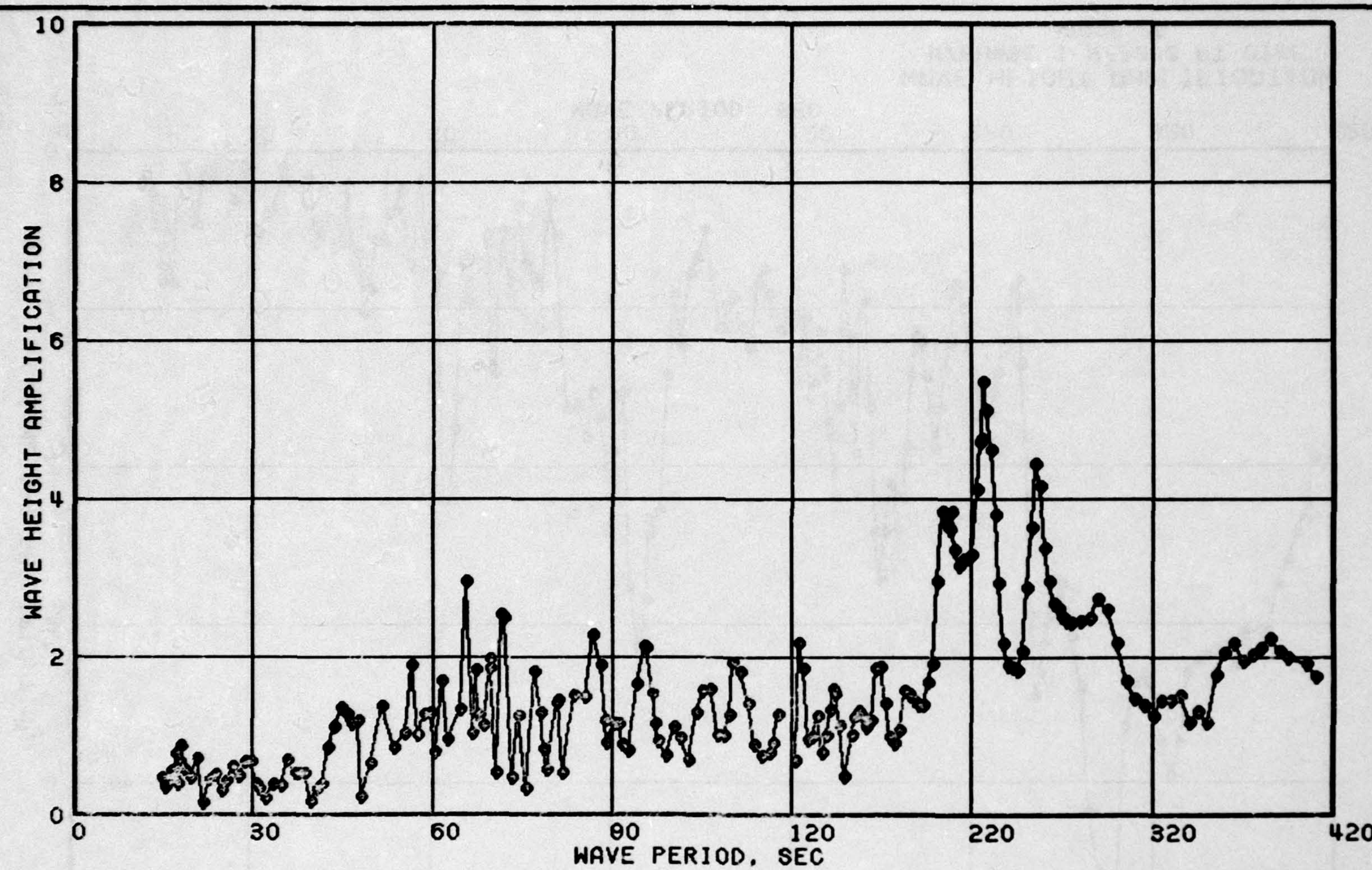
PLATE 54


WAVE HEIGHT AMPLIFICATION
0
1
2
3
4
5
0
30
60
90
120
220
320
420
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
M/PHASE I W/2000 FT DIKE
GAGE 15

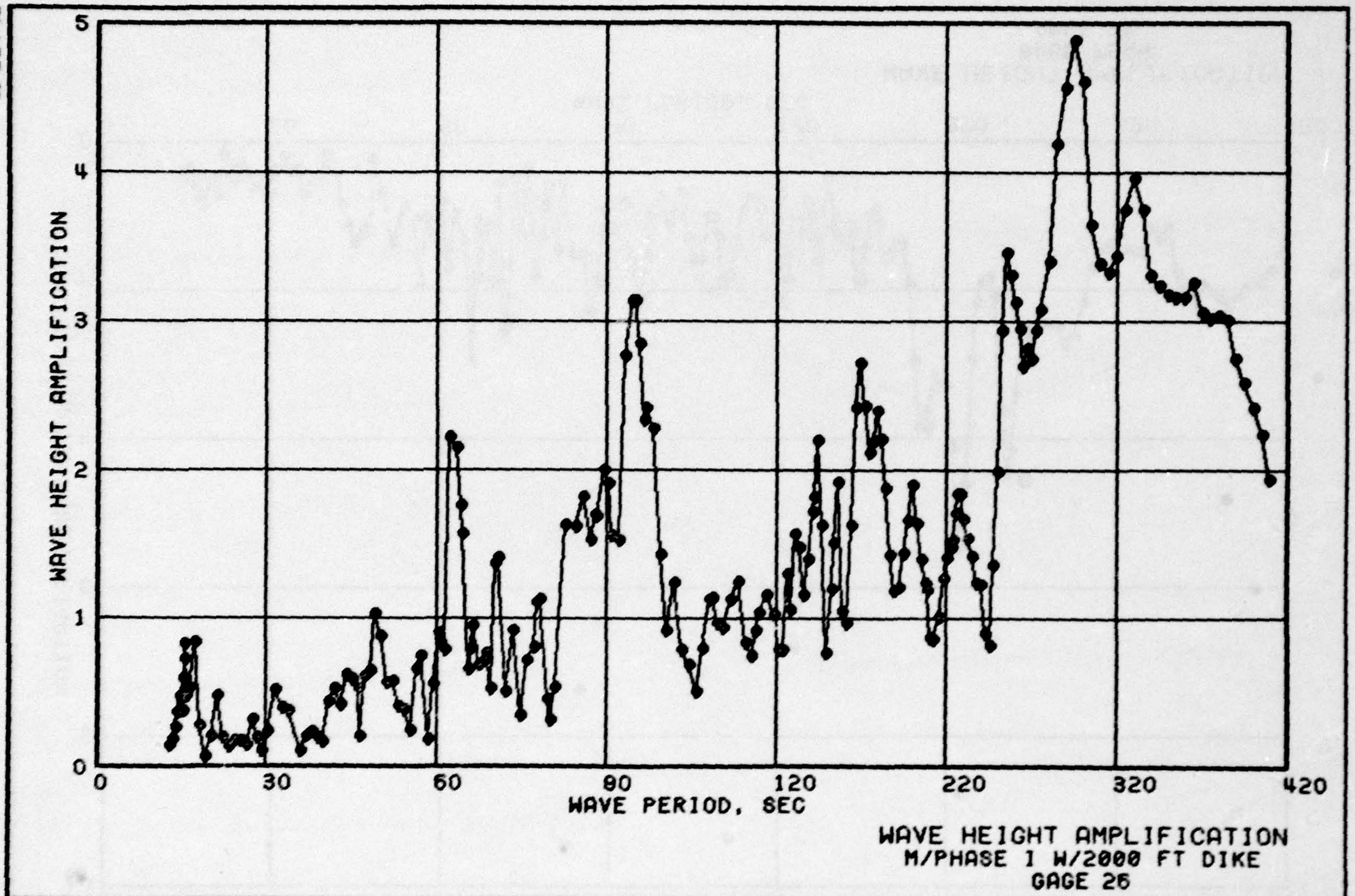


WAVE HEIGHT AMPLIFICATION
M/PHASE 1 W/2000 FT DIKE
GAGE 16
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
0
30
60
90
120
220
320
420
0
1
2
3
4
5

PLATE 56

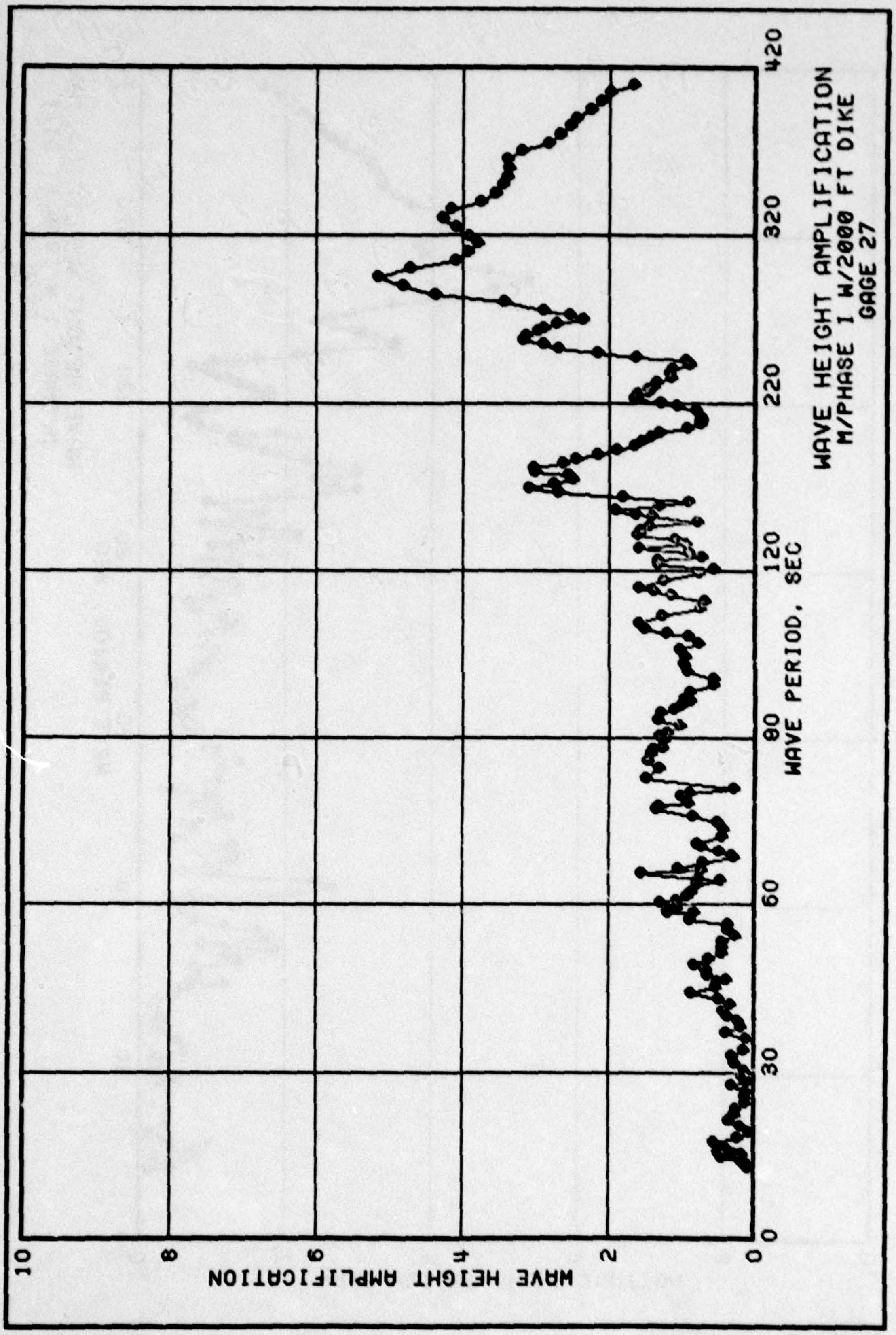


WAVE HEIGHT AMPLIFICATION
BASE PLAN
GAGE 25



WAVE HEIGHT AMPLIFICATION
0
1
2
3
4
5
0
30
60
90
120
220
320
420
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
M/PHASE I W/2000 FT DIKE
GAGE 26

PLATE 58


WAVE HEIGHT AMPLIFICATION
M/PHASE 1 W/2000 FT DIKE
GAGE 27
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
0
30
60
90
120
220
320
420
2
4
6
8
10

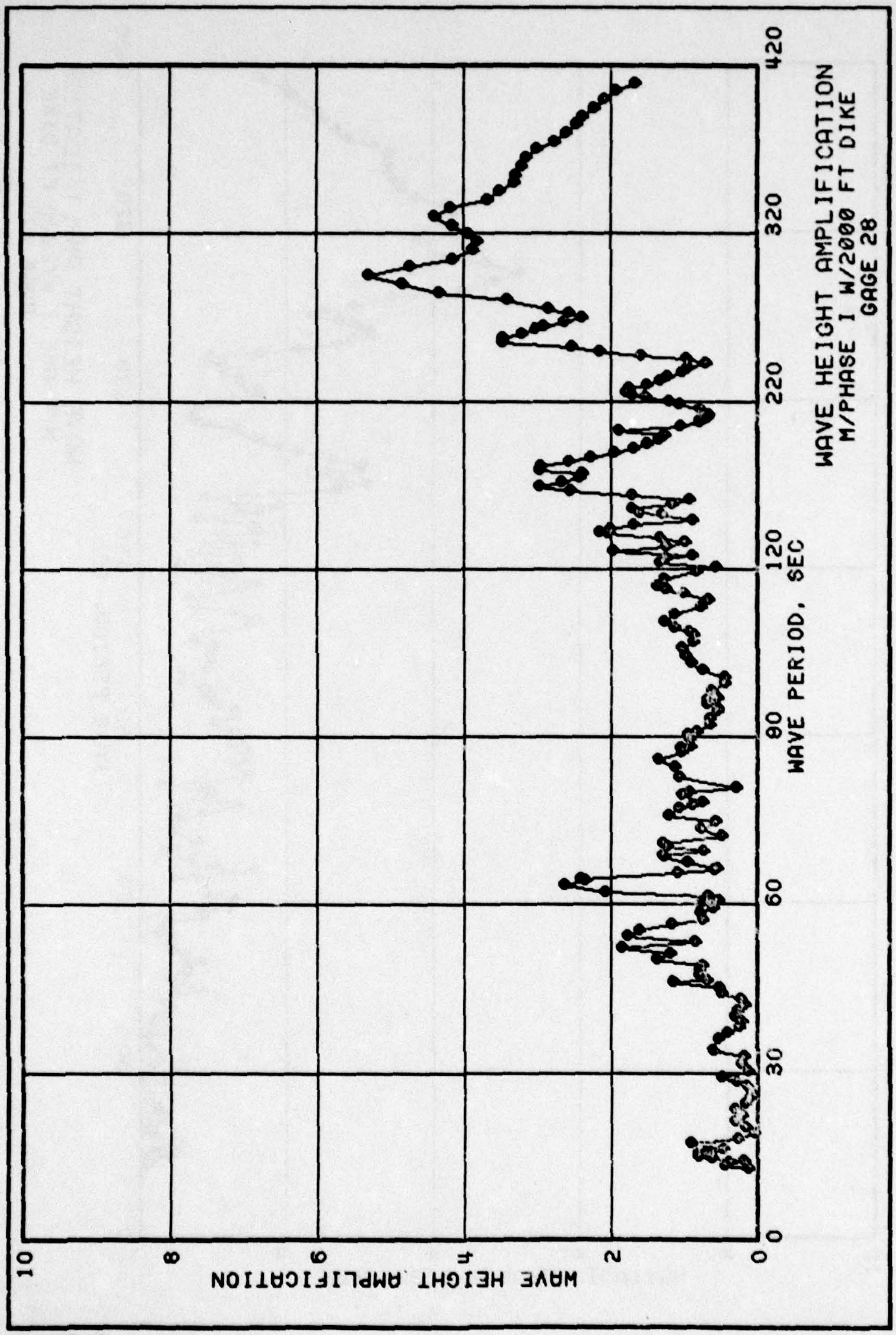
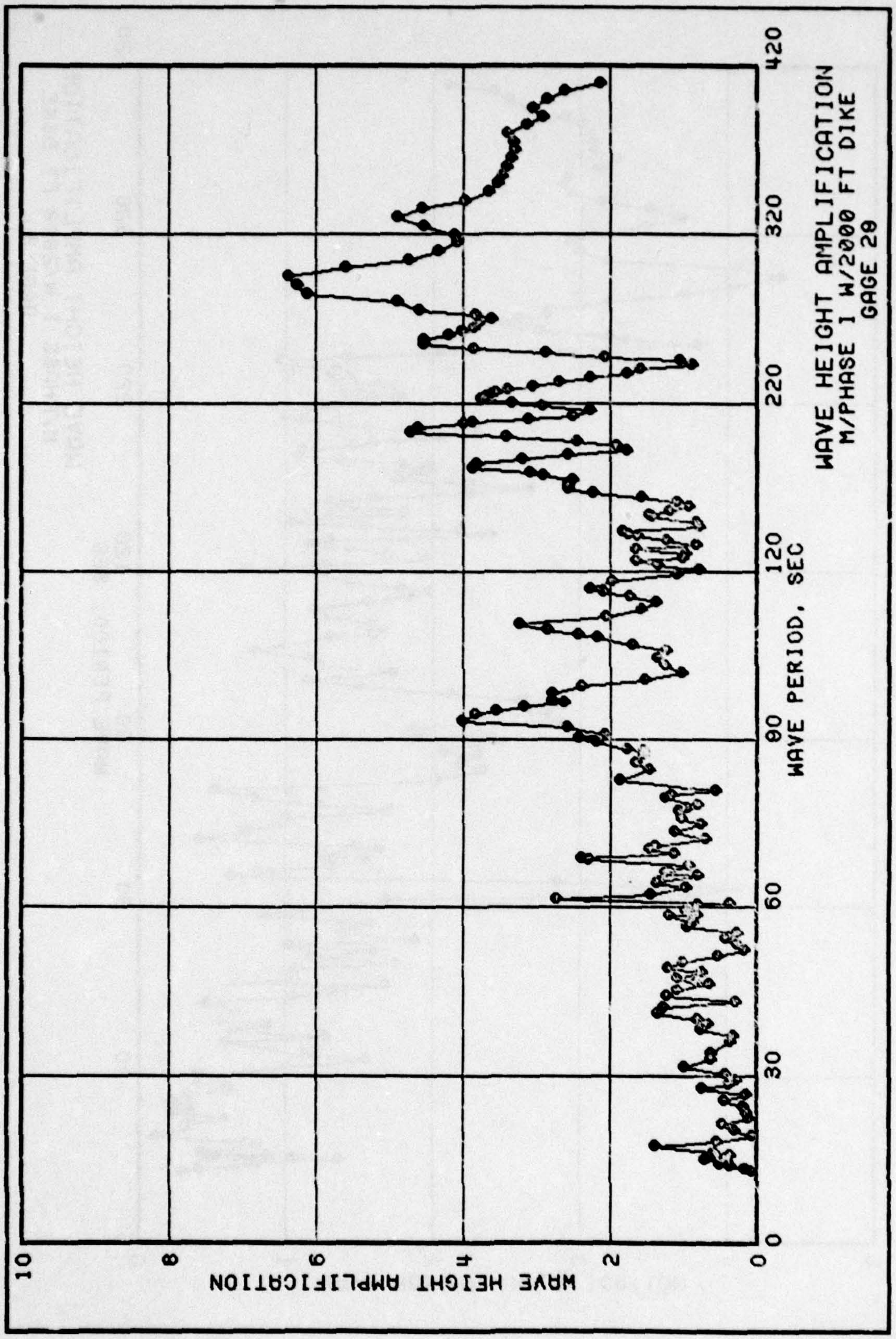
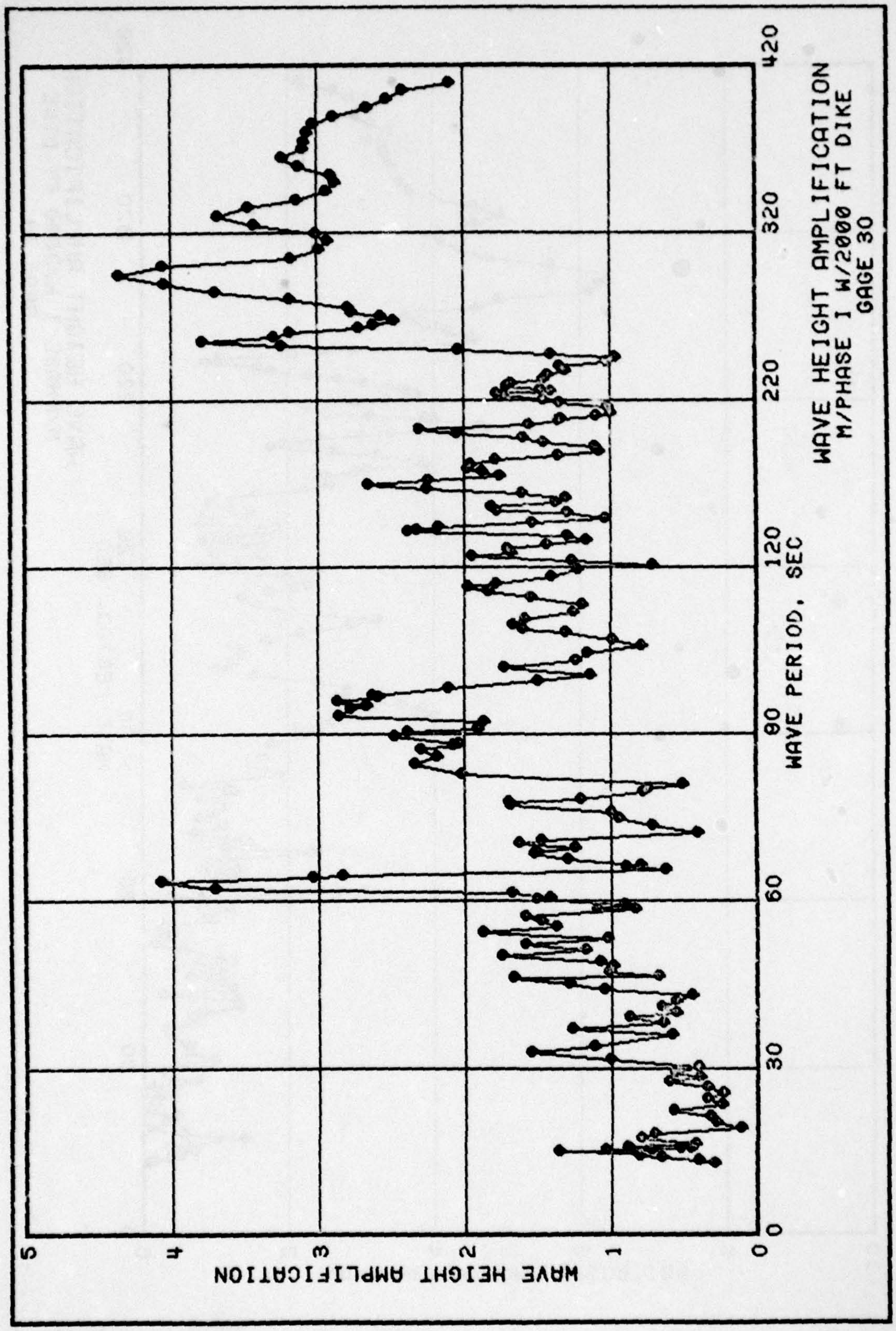

WAVE HEIGHT AMPLIFICATION
M/PHASE I W/2000 FT DIKE
GAGE 28
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
0
30
60
90
120
220
320
420
0
2
4
6
8
10

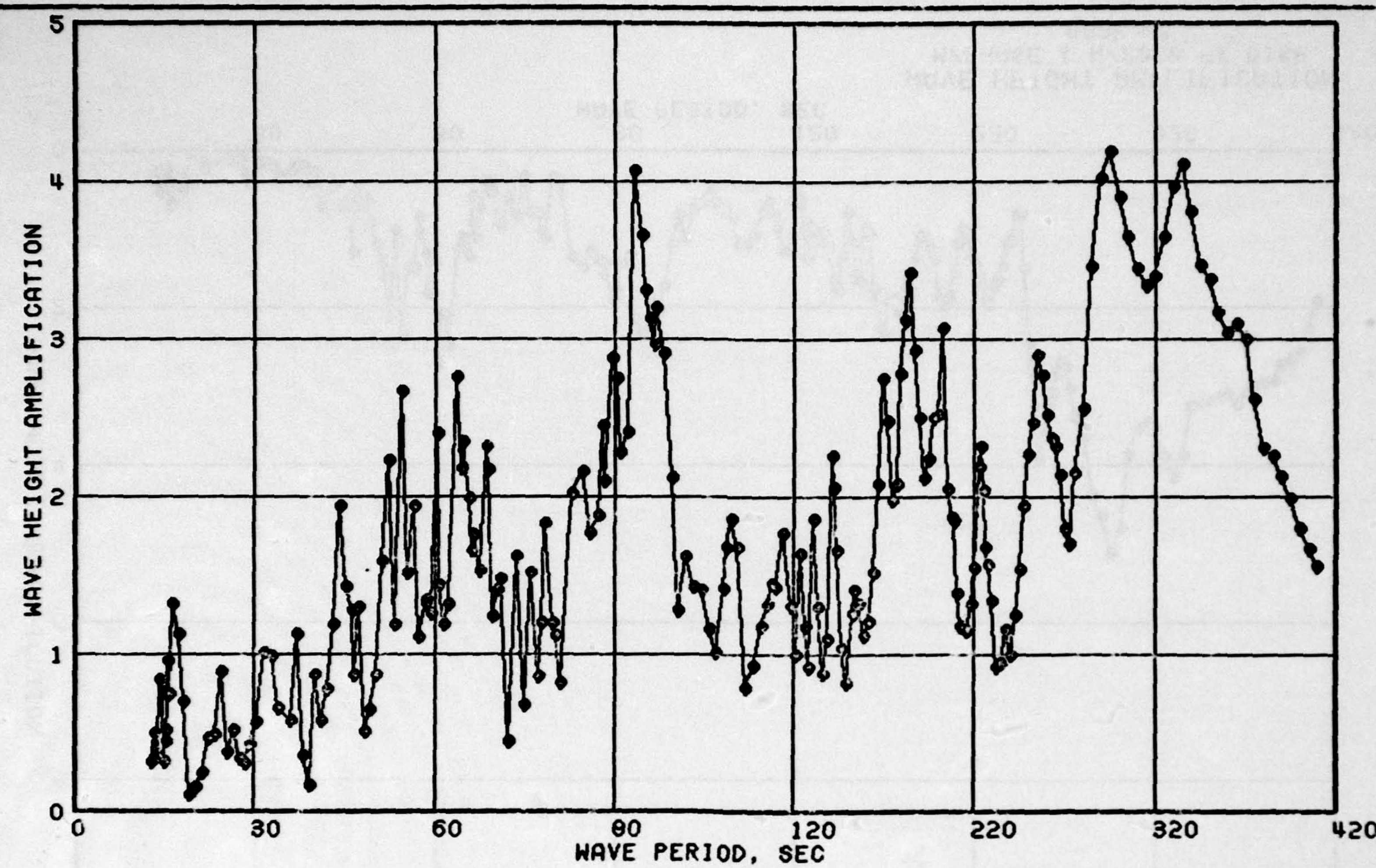
PLATE 60


WAVE HEIGHT AMPLIFICATION
M/PHASE 1 W/2000 FT DIKE
GAGE 20
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
0
2
4
6
8
10
0
30
60
90
120
220
320
420

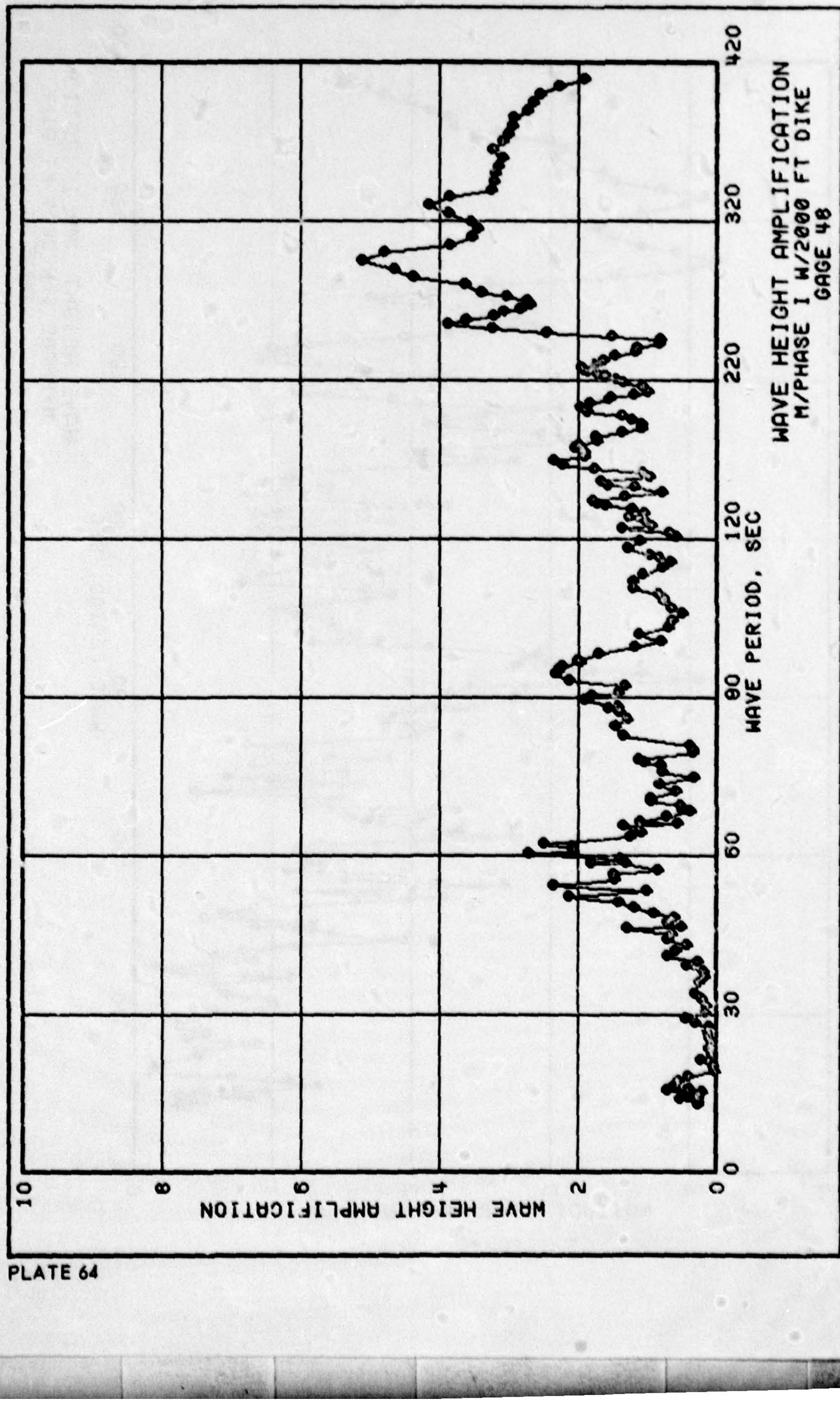


WAVE HEIGHT AMPLIFICATION
M/PHASE 1 W/2000 FT DIKE
GAGE 30
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
0
30
60
90
120
220
320
420
0
1
2
3
4
5

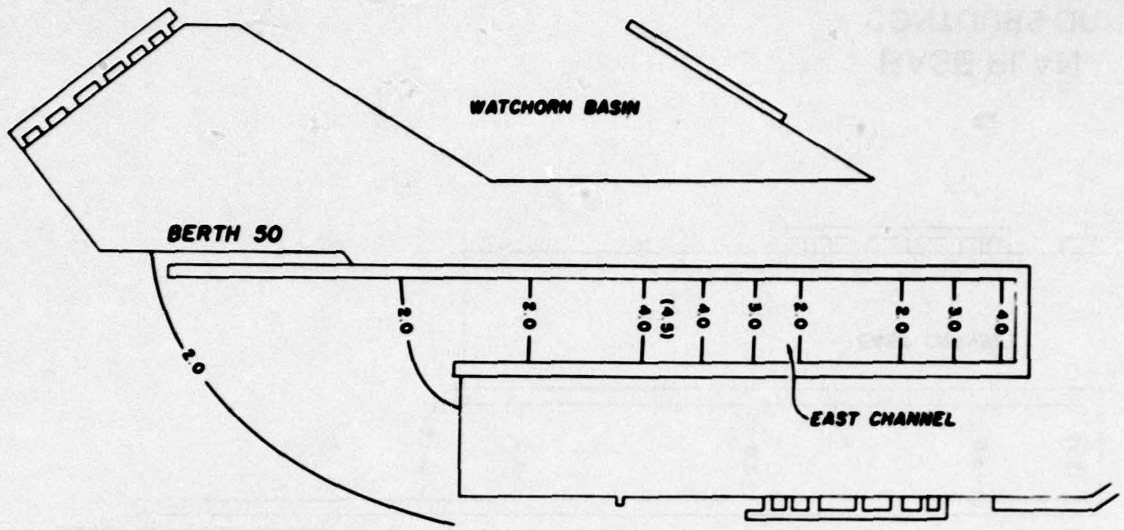
PLATE 62



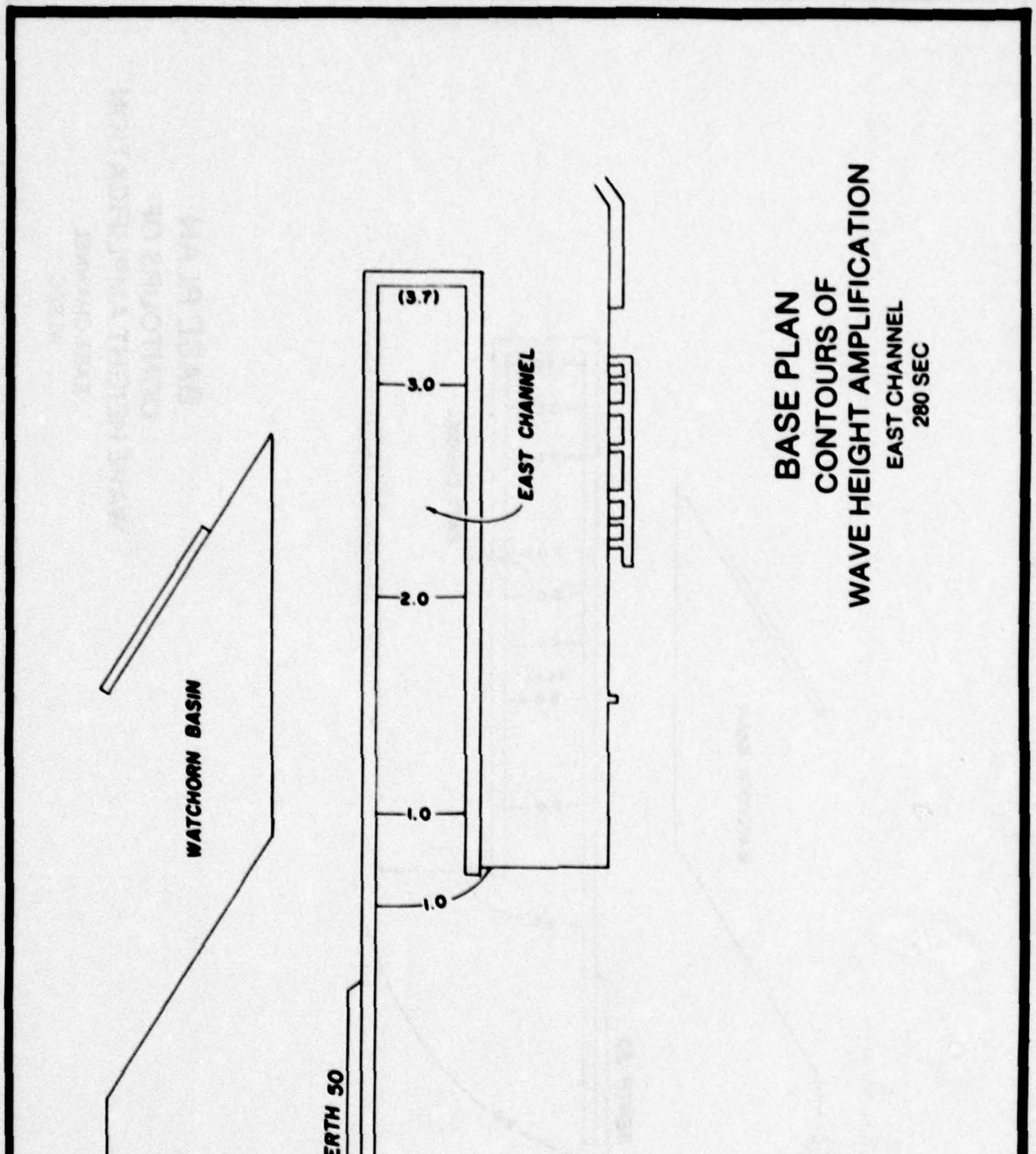
WAVE HEIGHT AMPLIFICATION
M/PHASE I W/2000 FT DIKE
GAGE 31



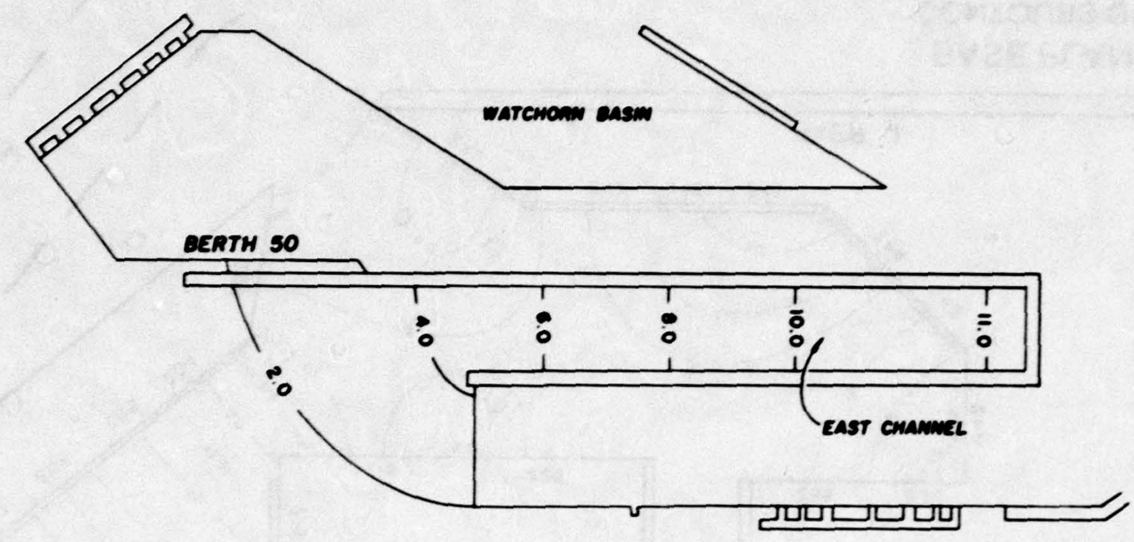
WAVE HEIGHT AMPLIFICATION
M/PHASE I W/2000 FT DIKE
GAGE 48
WAVE PERIOD, SEC
WAVE HEIGHT AMPLIFICATION
0
30
60
90
120
220
320
420
0
2
4
6
8
10



BASE PLAN
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
EAST CHANNEL
96 SEC



BASE PLAN
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
EAST CHANNEL
280 SEC



BASE PLAN
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
EAST CHANNEL
385 SEC

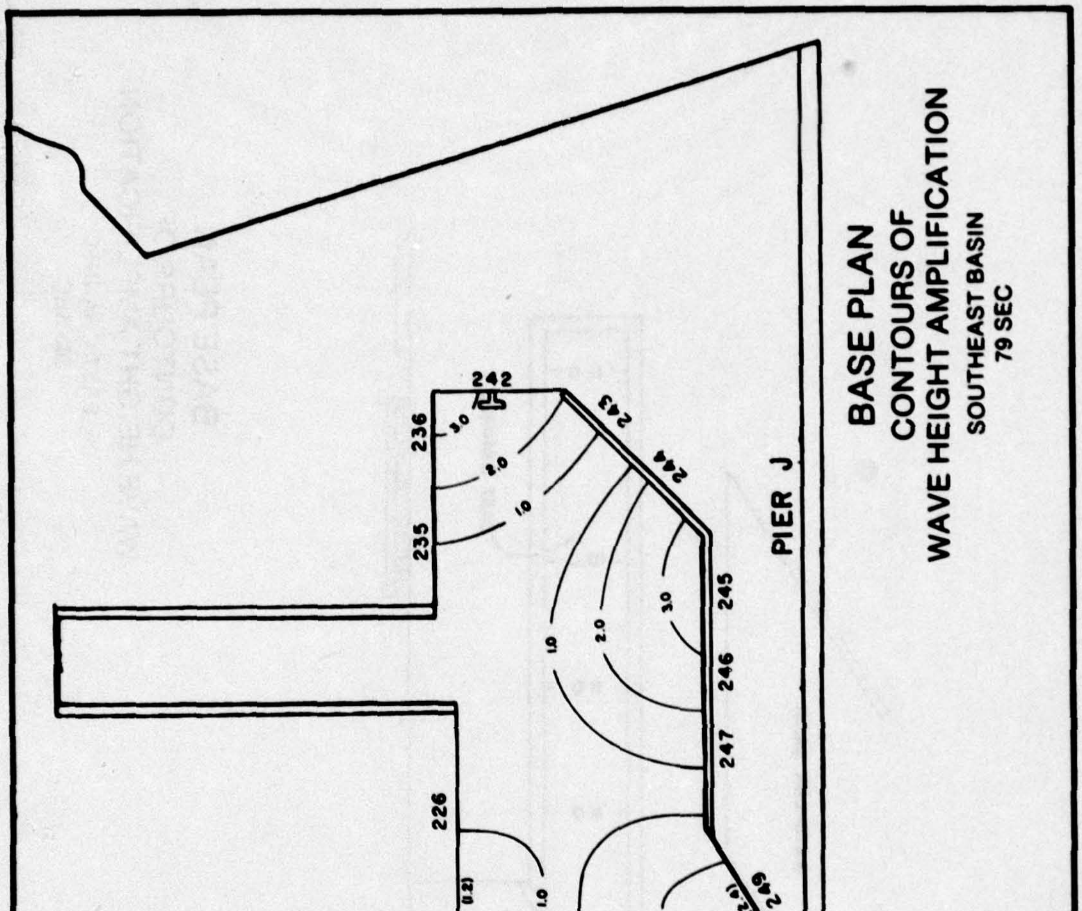
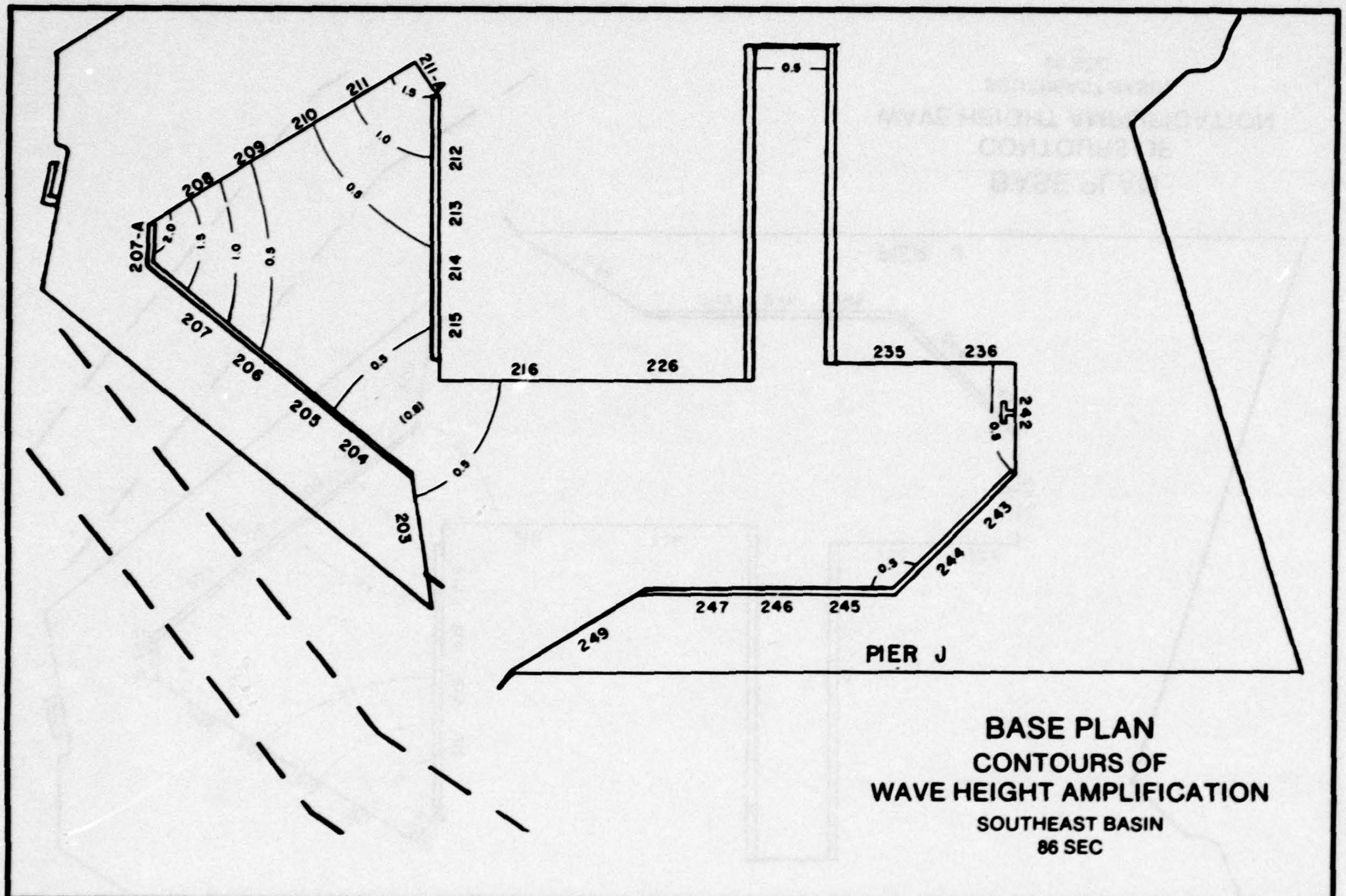
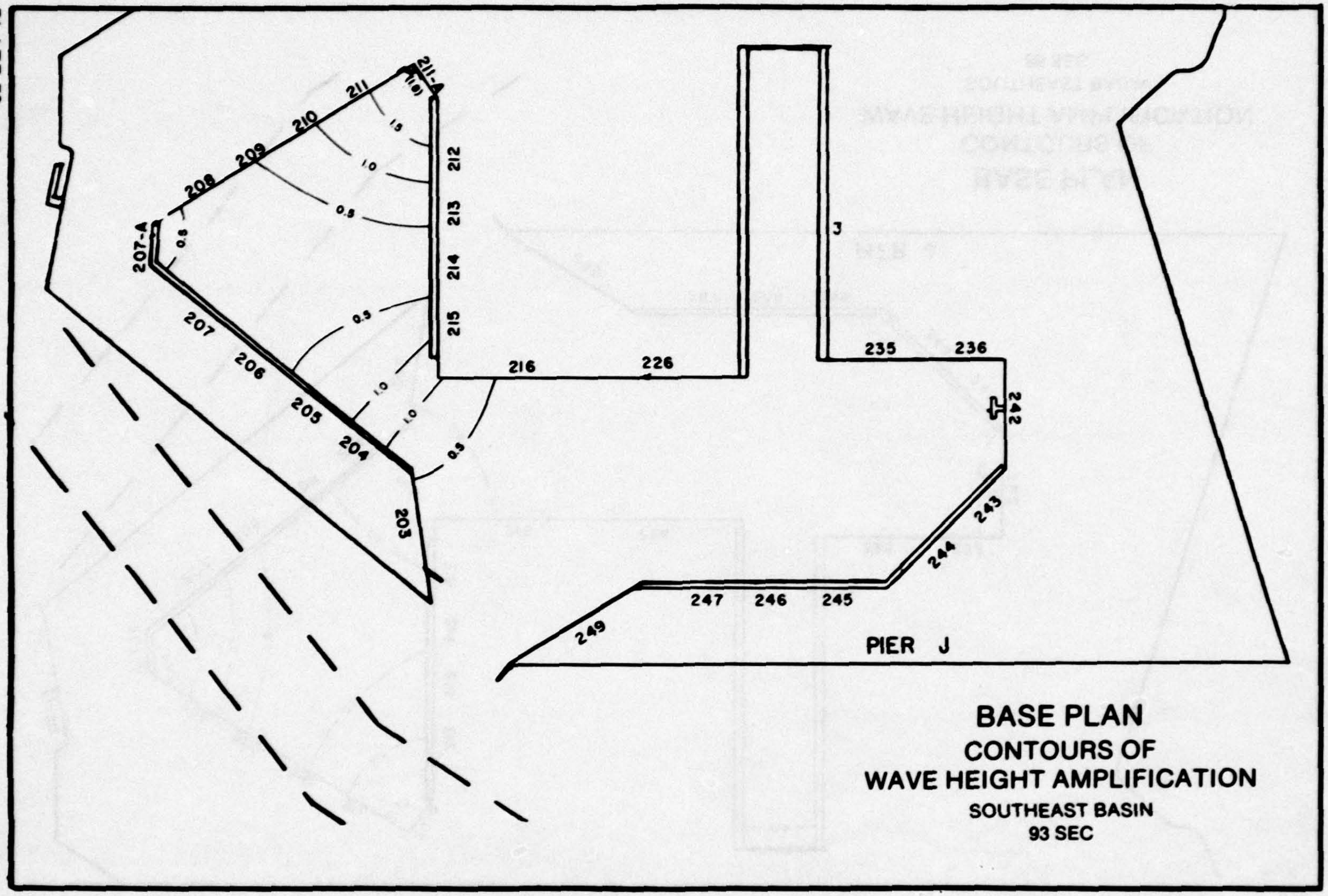

BASE PLAN
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
SOUTHEAST BASIN
79 SEC
PIER J
207-A
207
206
205
204
203
208
209
210
211
211-A
212
213
214
215
216
226
235
236
242
243
244
245
246
247
249
4.0
3.0
2.0
1.0
(3.5)
(1.2)
(2.1)

PLATE 68

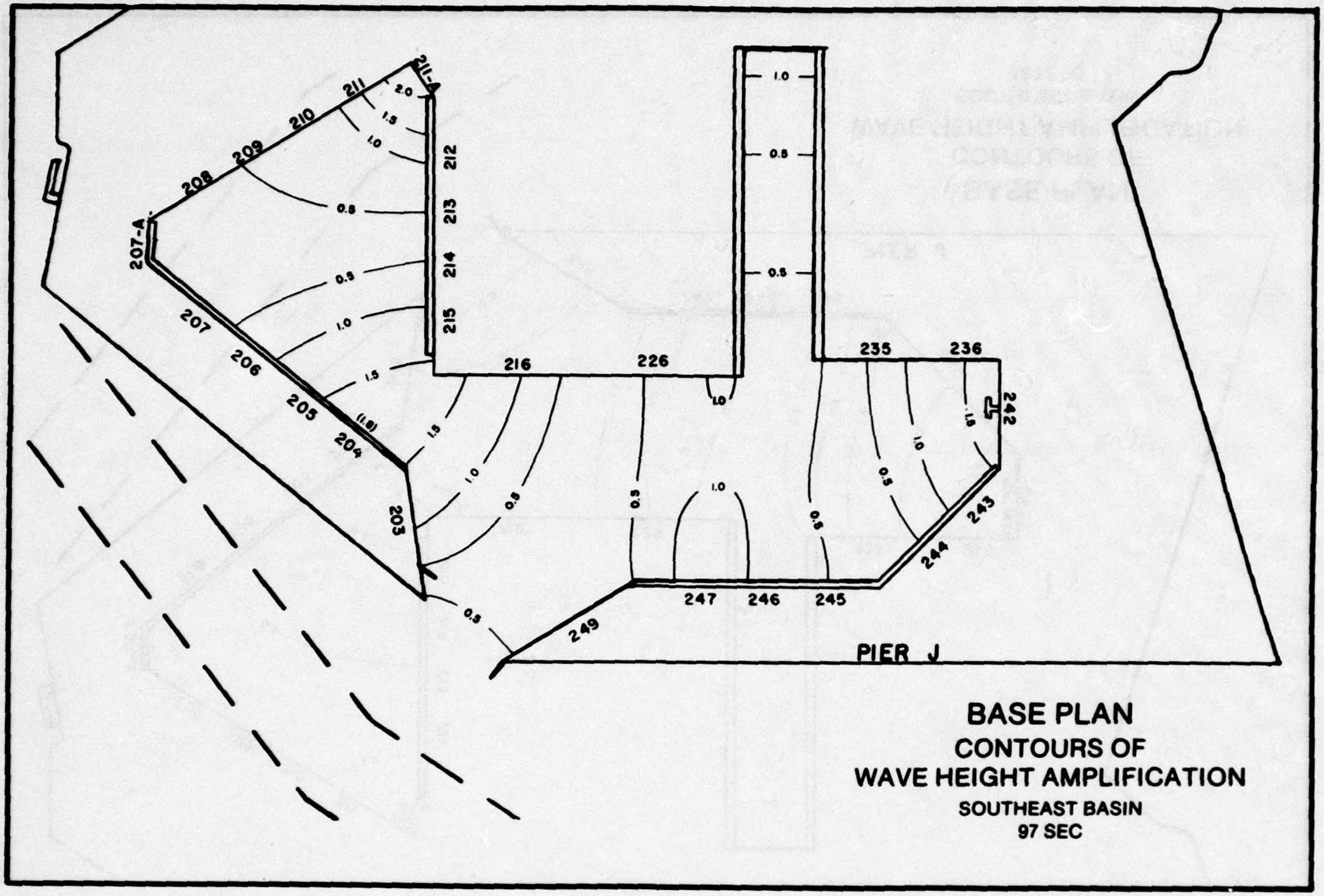


BASE PLAN
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
SOUTHEAST BASIN
86 SEC

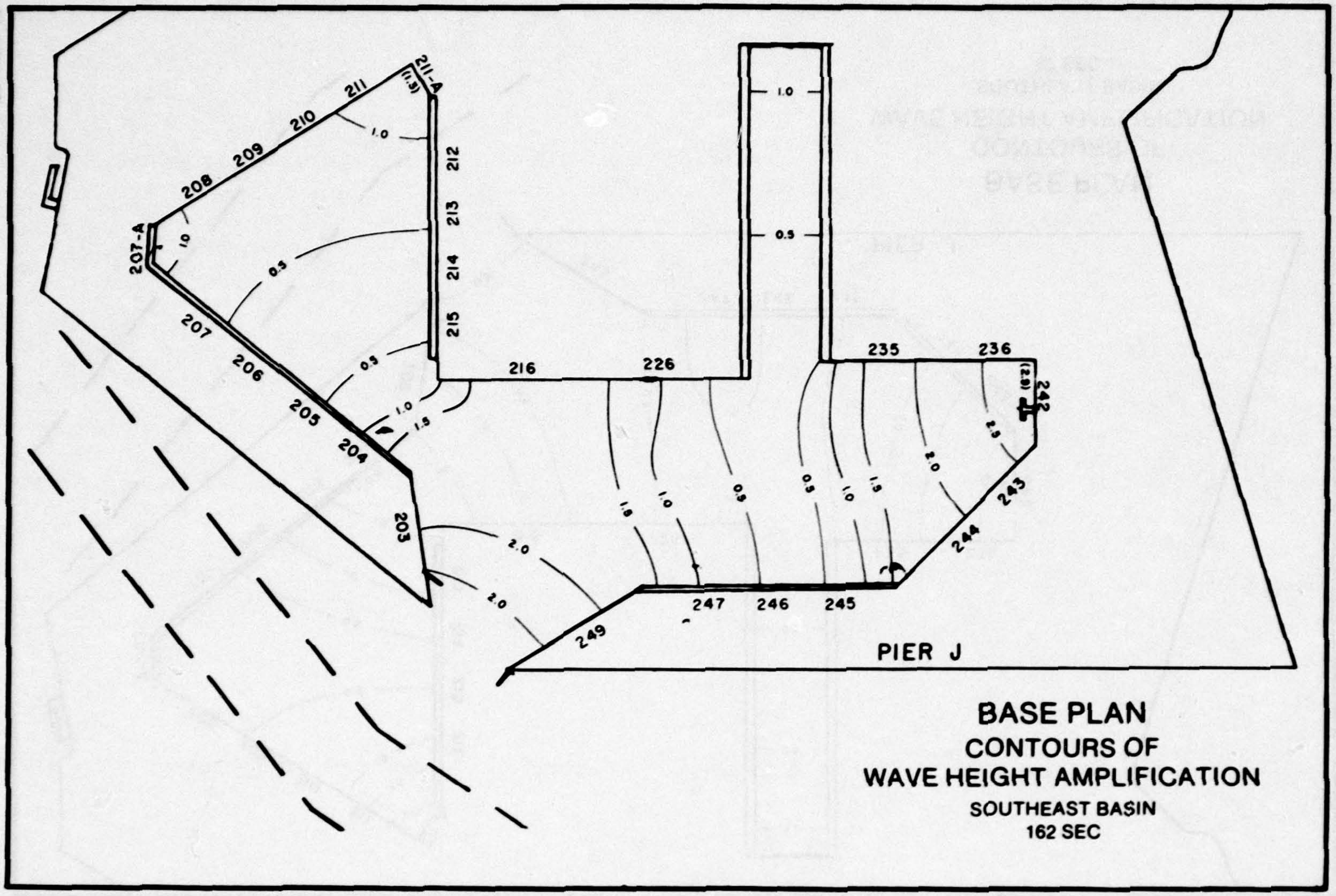


BASE PLAN
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
SOUTHEAST BASIN
93 SEC

PLATE 70

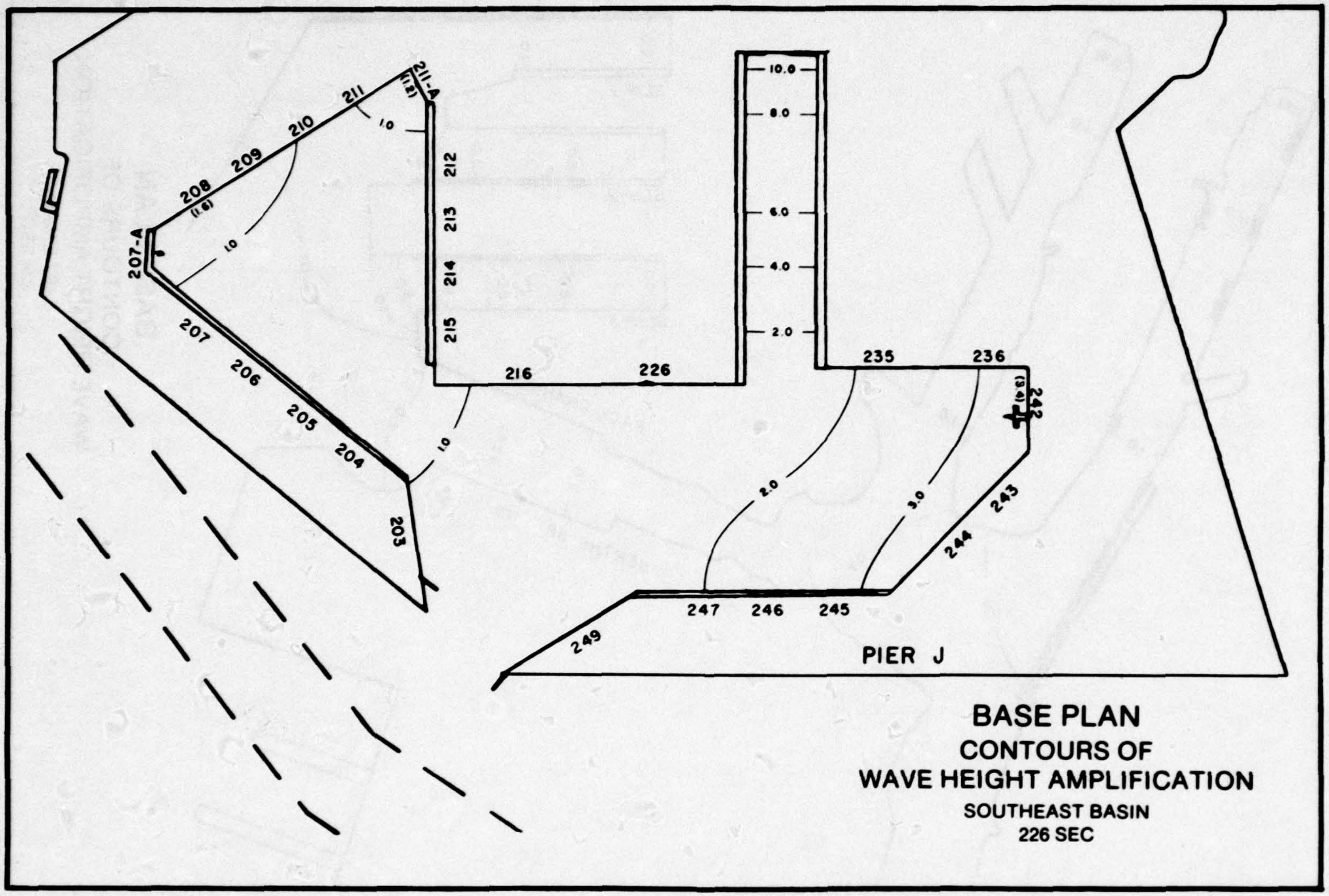


BASE PLAN
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
SOUTHEAST BASIN
97 SEC

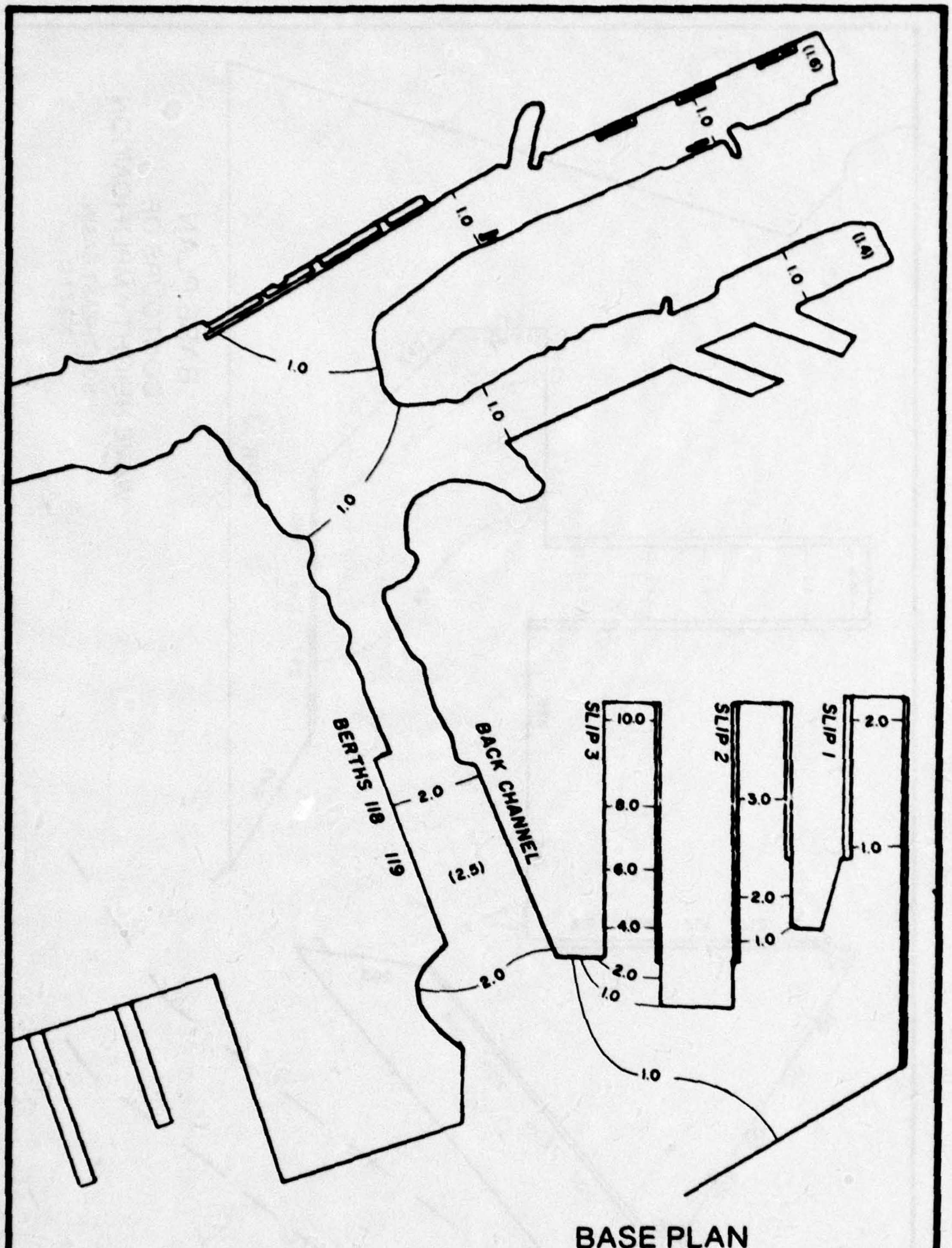


BASE PLAN
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
SOUTHEAST BASIN
162 SEC

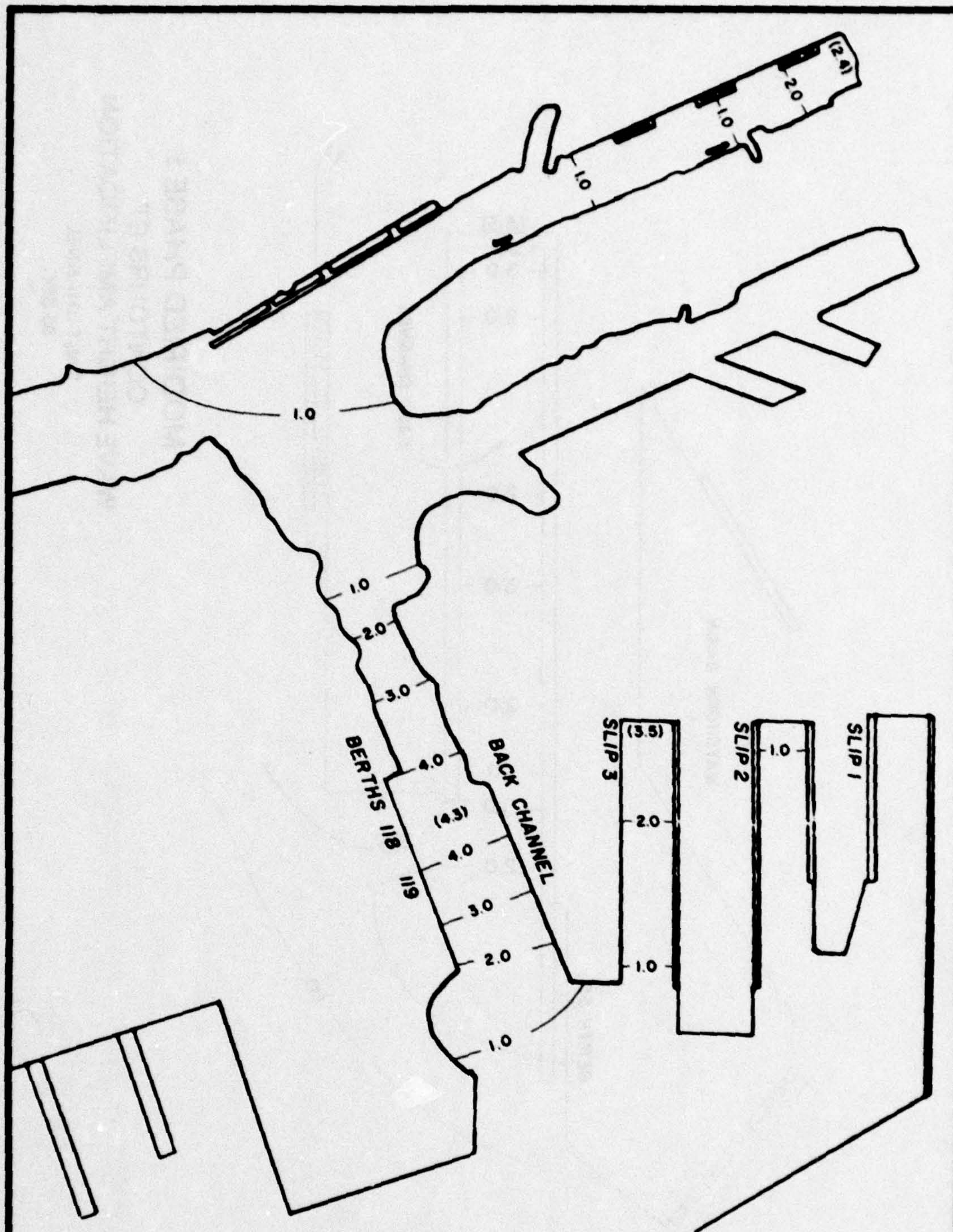
PLATE 72



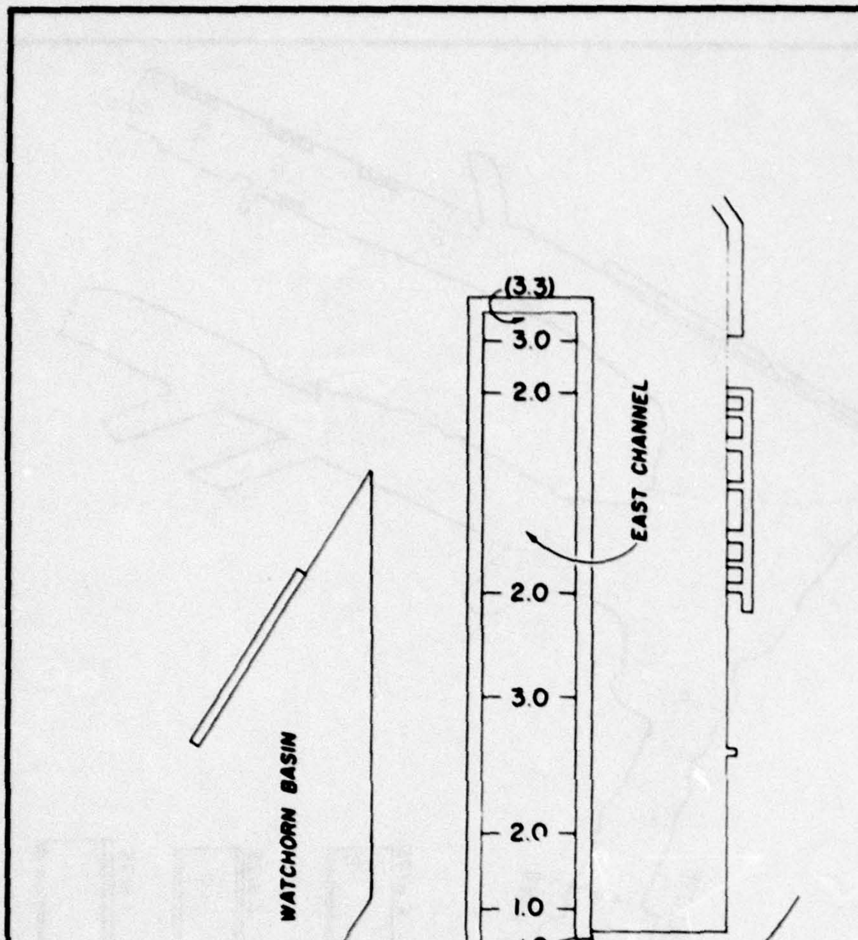
BASE PLAN
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
SOUTHEAST BASIN
226 SEC



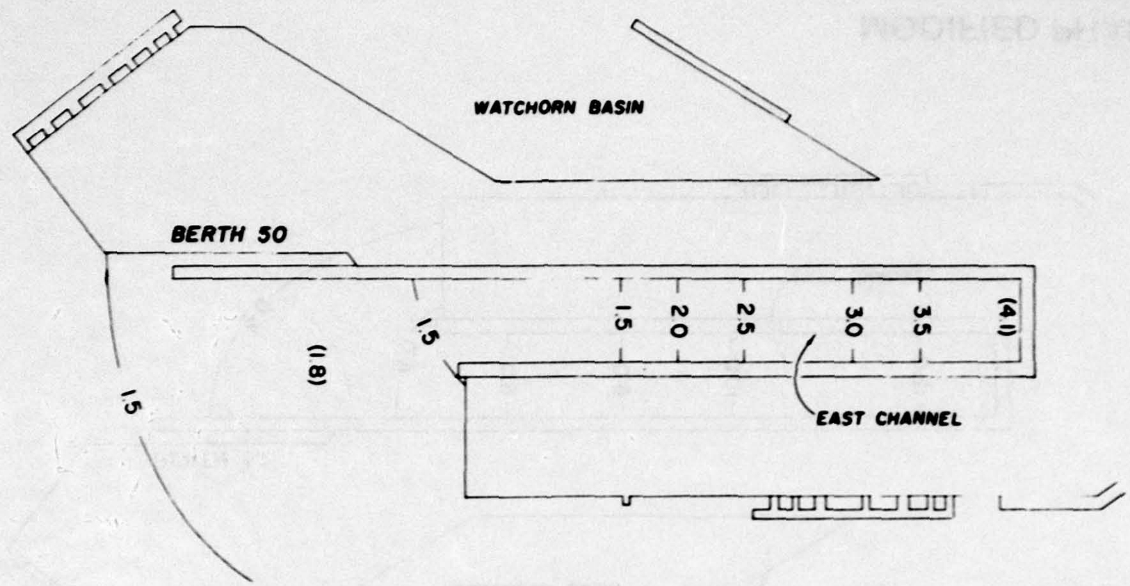
BASE PLAN
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
EAST BASIN
224 SEC



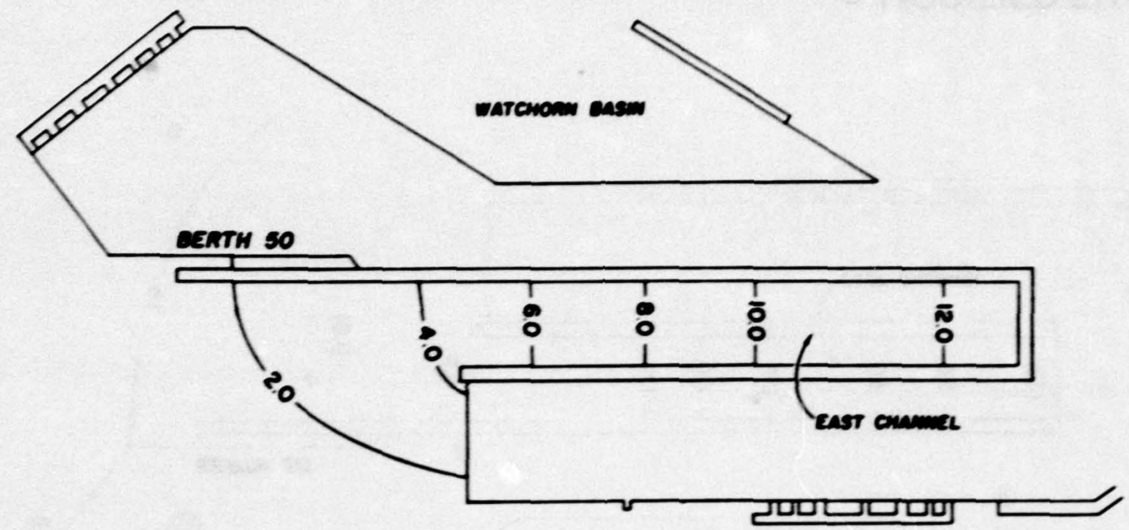
BASE PLAN
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
BACK CHANNEL
204 SEC



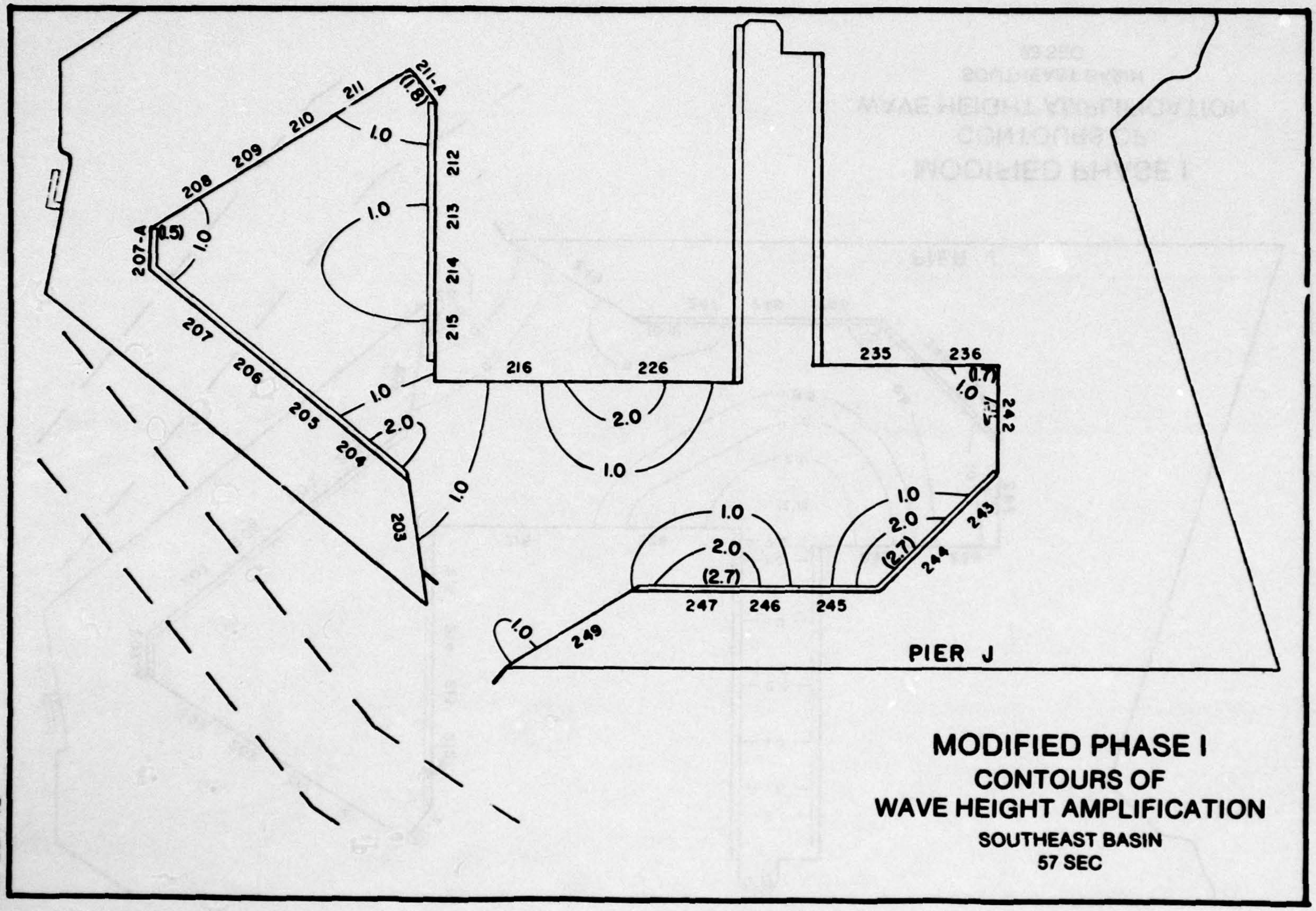
MODIFIED PHASE I
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
EAST CHANNEL
95 SEC



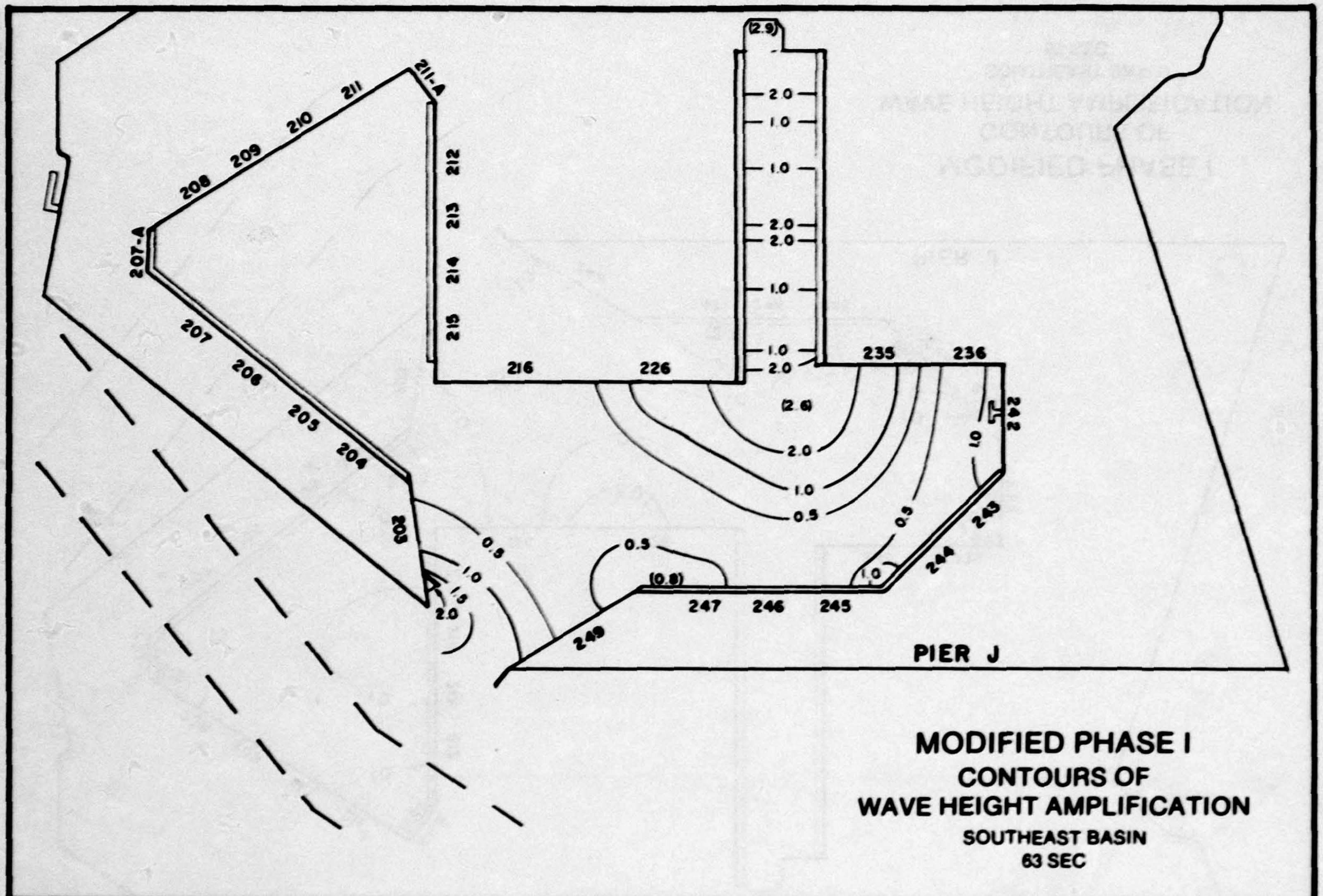
MODIFIED PHASE I
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
EAST CHANNEL
265 SEC



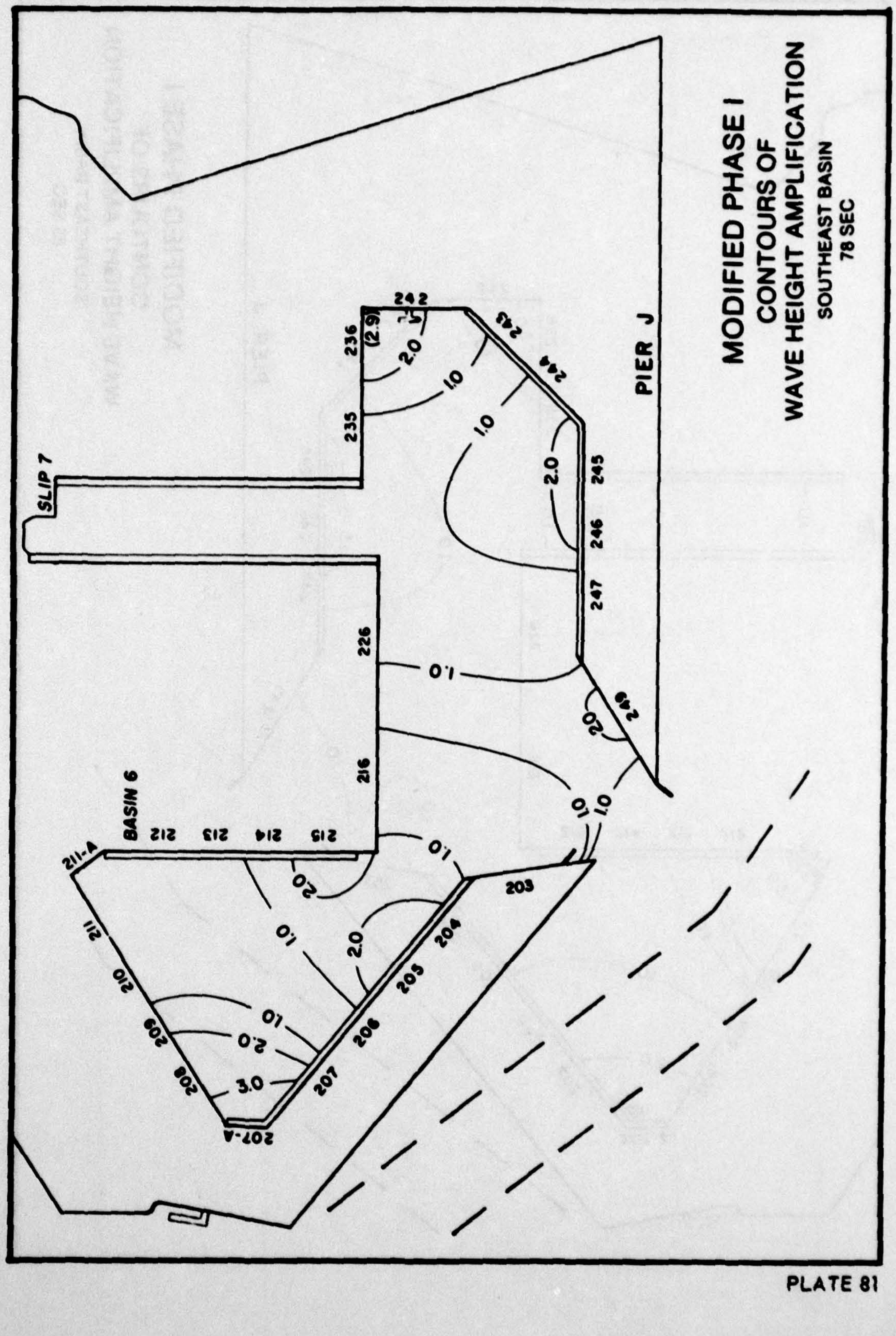
MODIFIED PHASE I
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
EAST CHANNEL
370 SEC



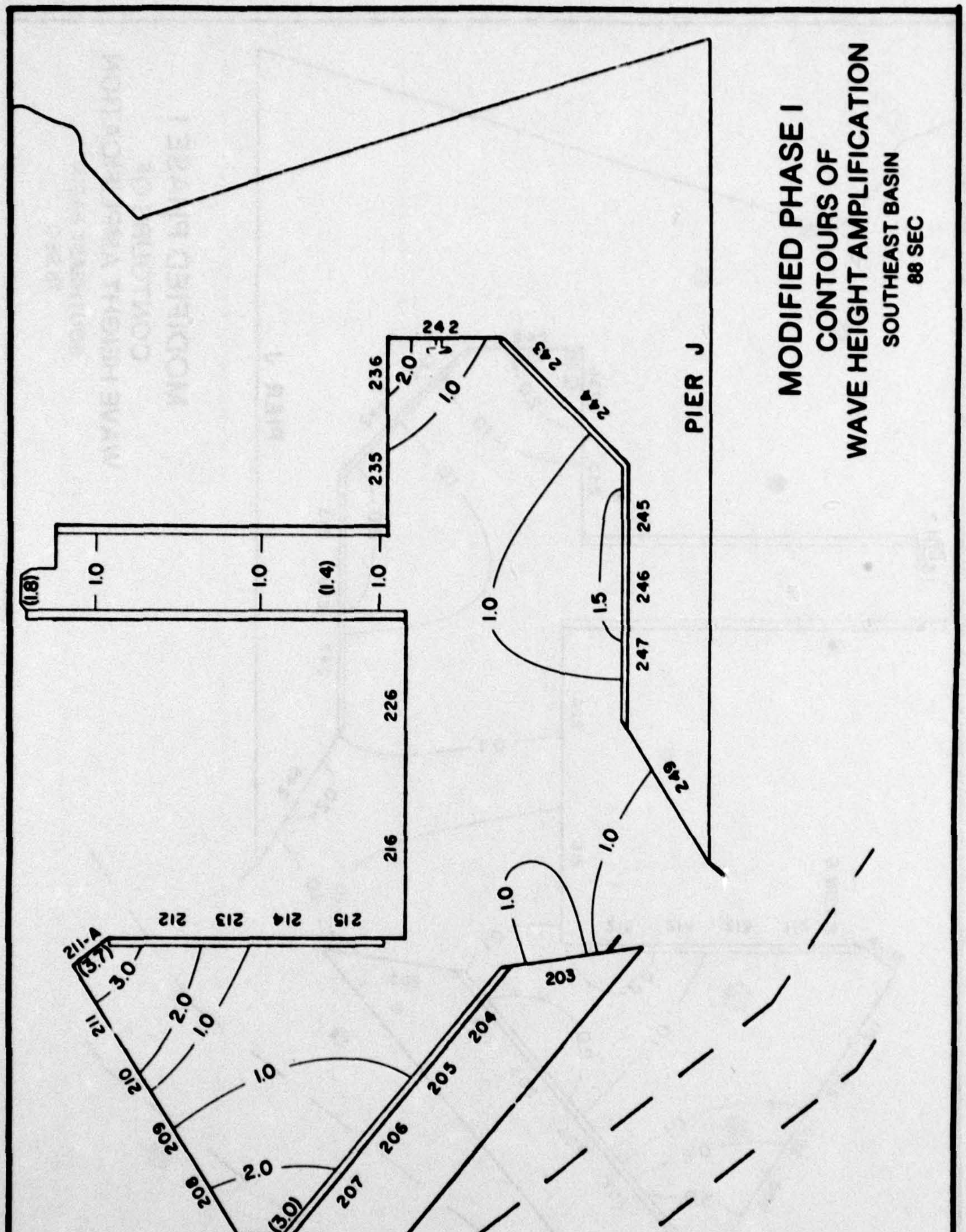
MODIFIED PHASE I
CONTOURS OF WAVE HEIGHT AMPLIFICATION
SOUTHEAST BASIN
57 SEC



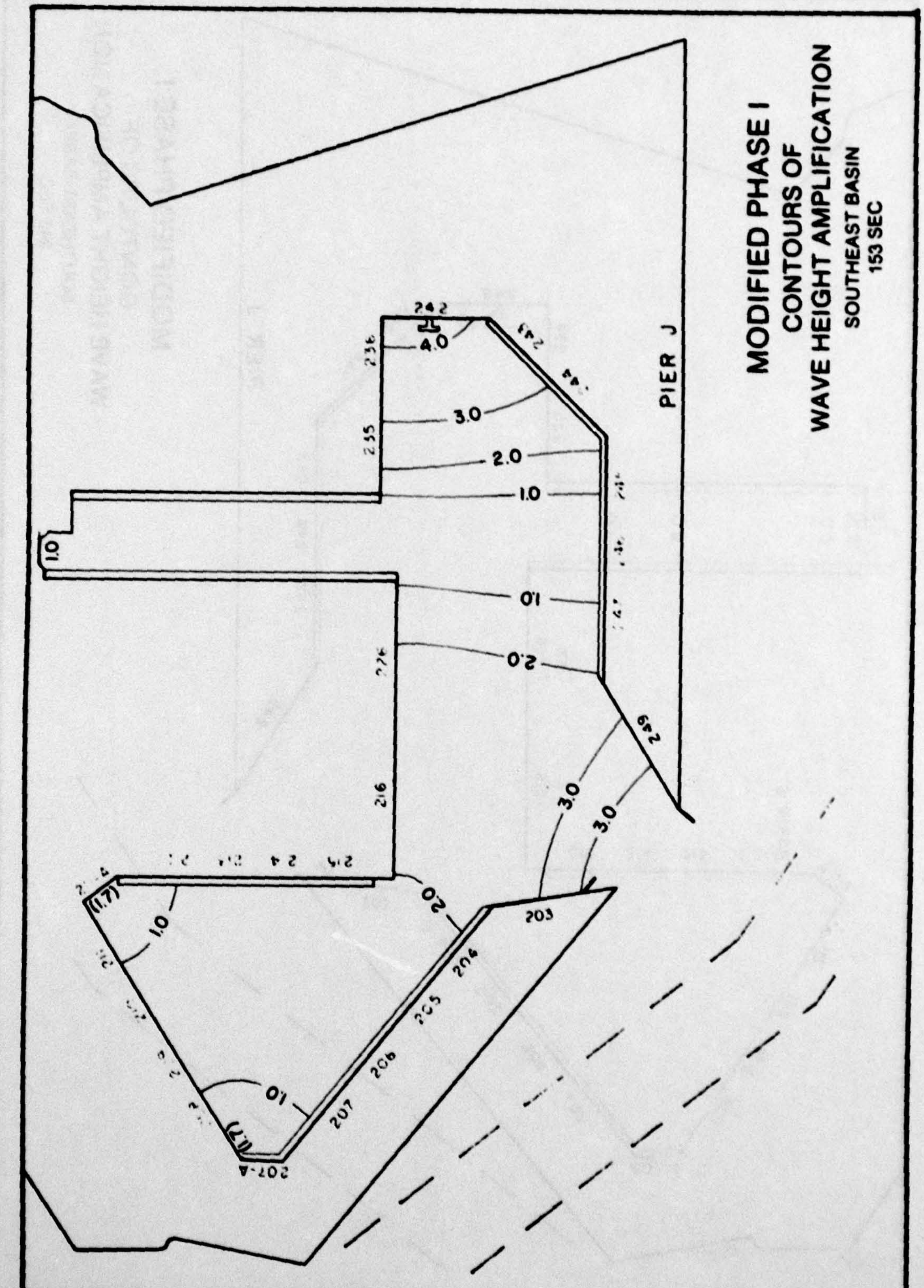
MODIFIED PHASE I
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
SOUTHEAST BASIN
63 SEC



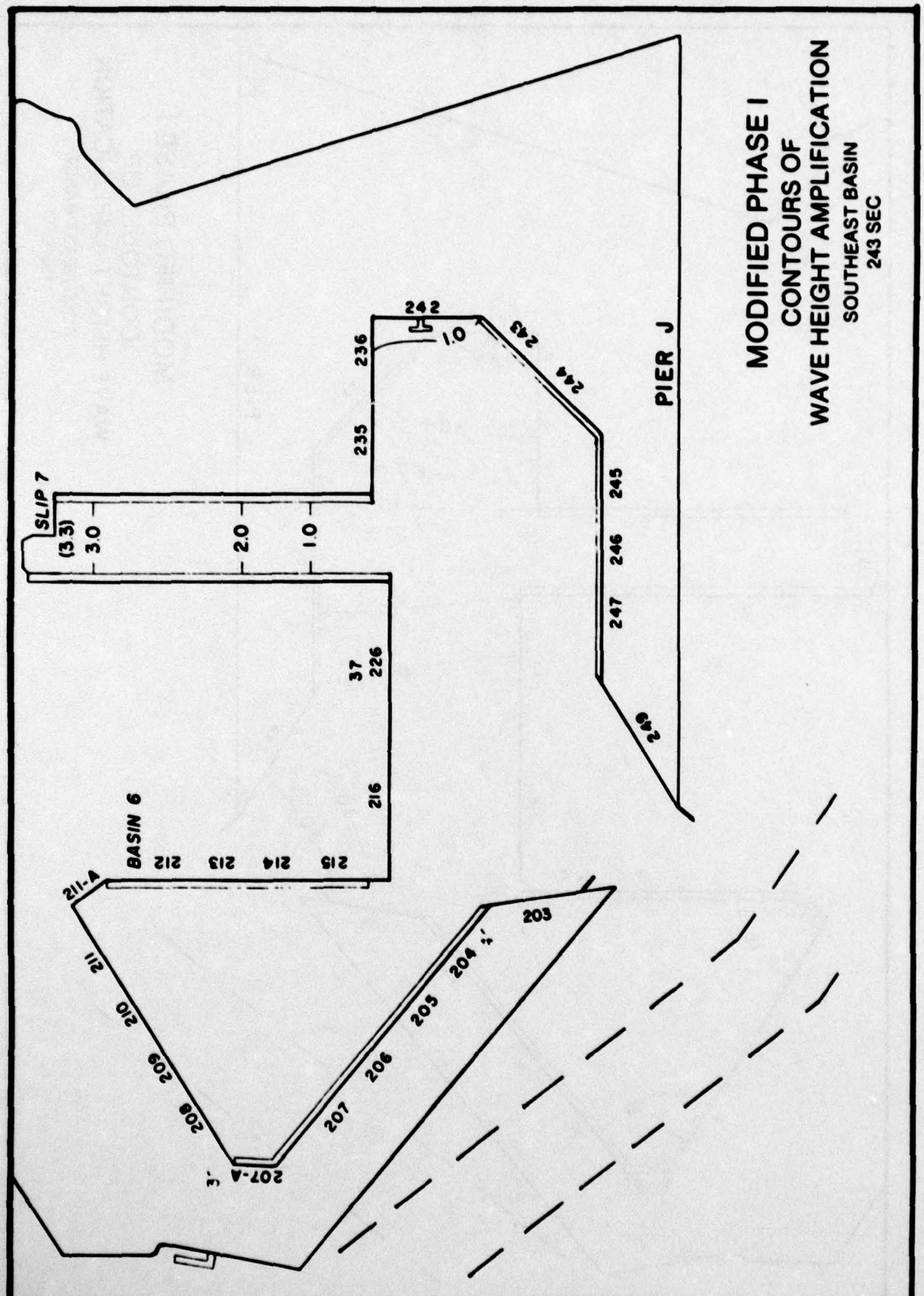
MODIFIED PHASE I
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
SOUTHEAST BASIN
78 SEC

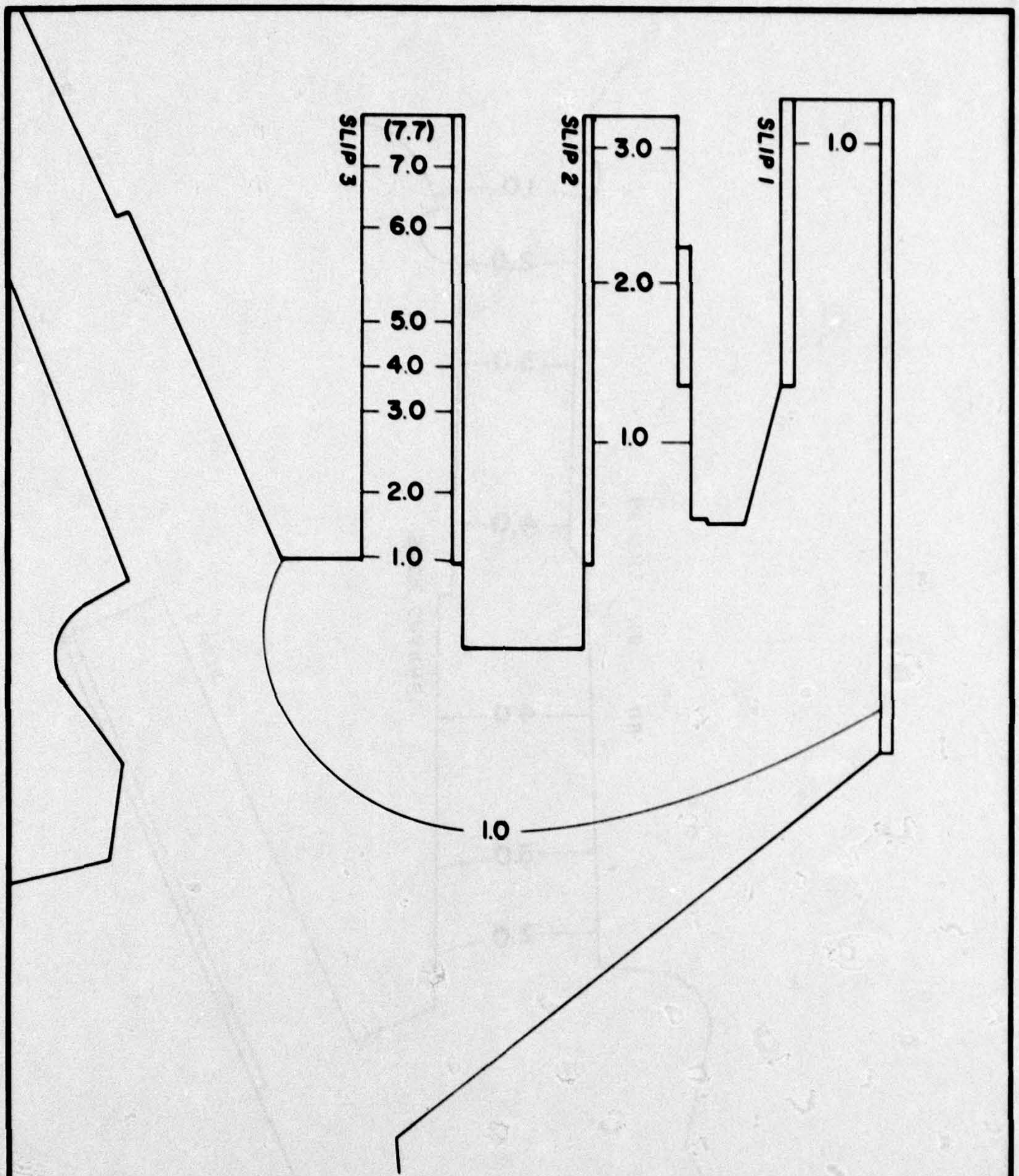


MODIFIED PHASE I
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
SOUTHEAST BASIN
88 SEC

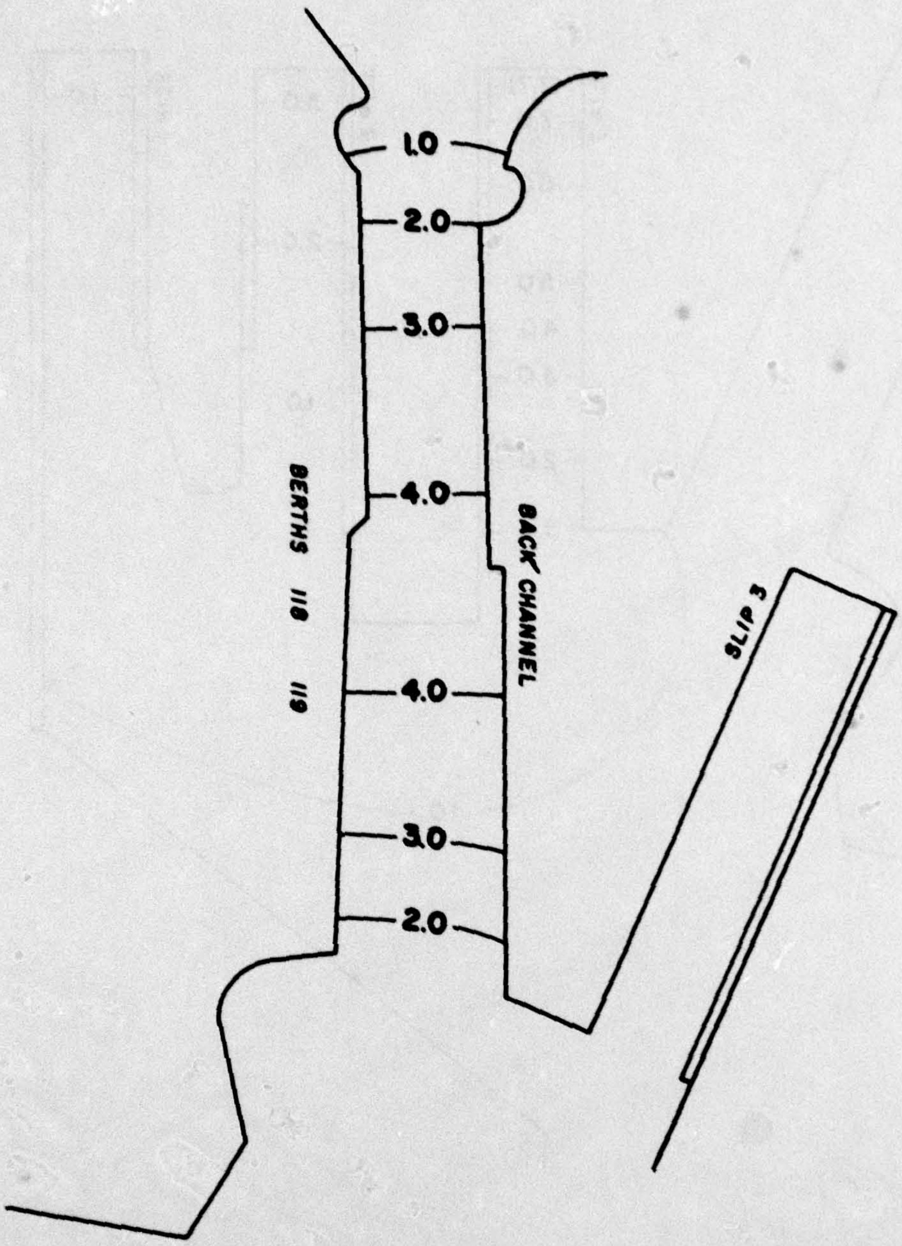


MODIFIED PHASE I
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
SOUTHEAST BASIN
153 SEC


MODIFIED PHASE I
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
SOUTHEAST BASIN
243 SEC
SLIP 7
(3.3)
3.0
2.0
1.0
BASIN 6
PIER J
211-A
211
210
209
208
207-A
207
206
205
204
203
212
213
214
215
216
37
226
235
236
242
243
244
245
246
247
249

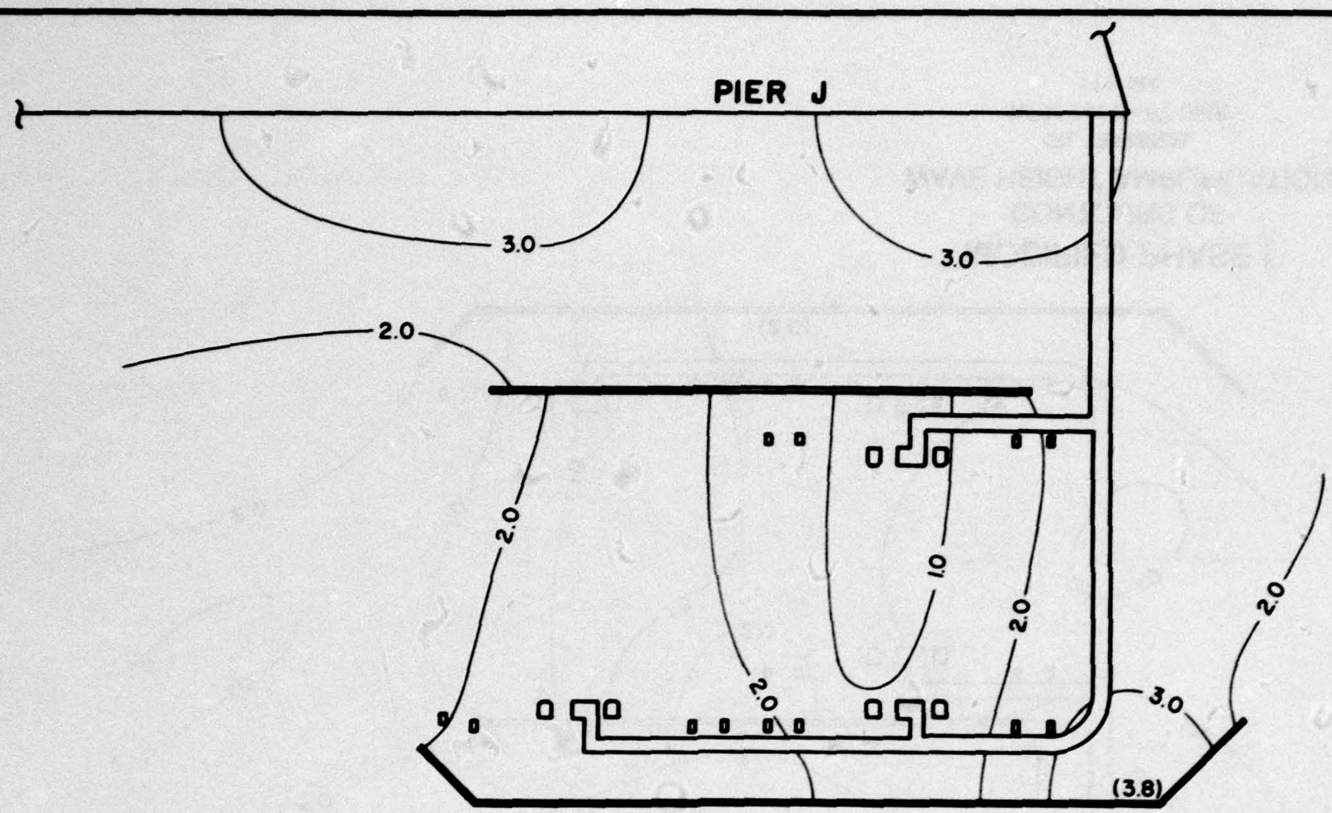


MODIFIED PHASE I
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
EAST BASIN
218 SEC



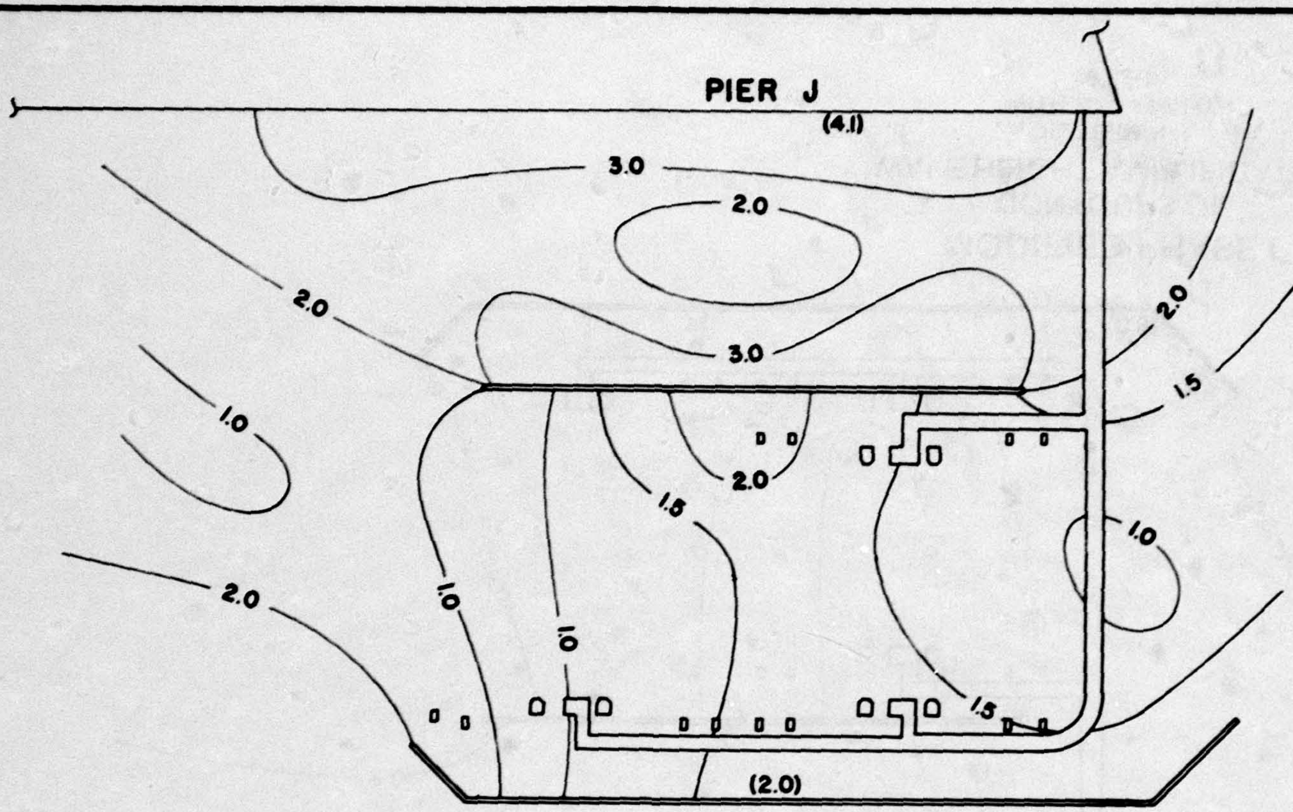
MODIFIED PHASE I
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
BACK CHANNEL
203 SEC

PLATE 86

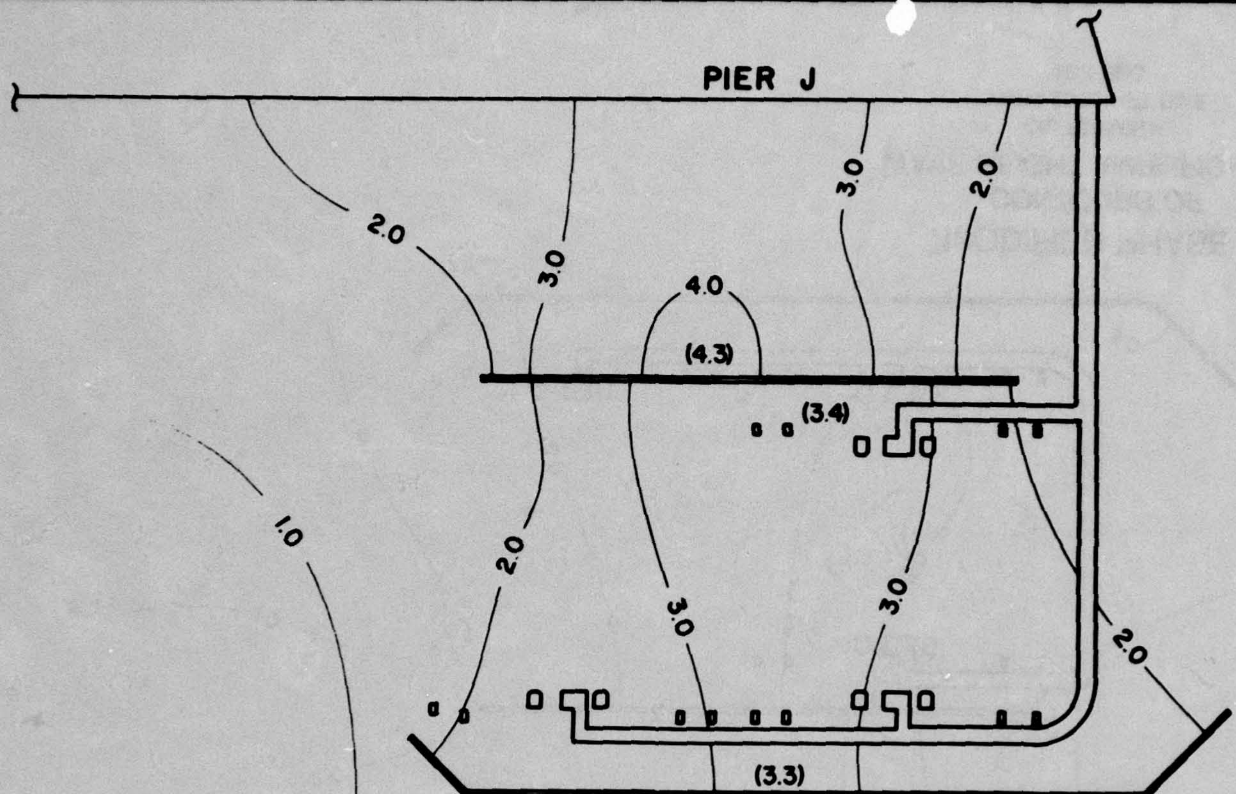


MODIFIED PHASE I
CONTOURS OF
WAVE HEIGHT AMPLIFICATION

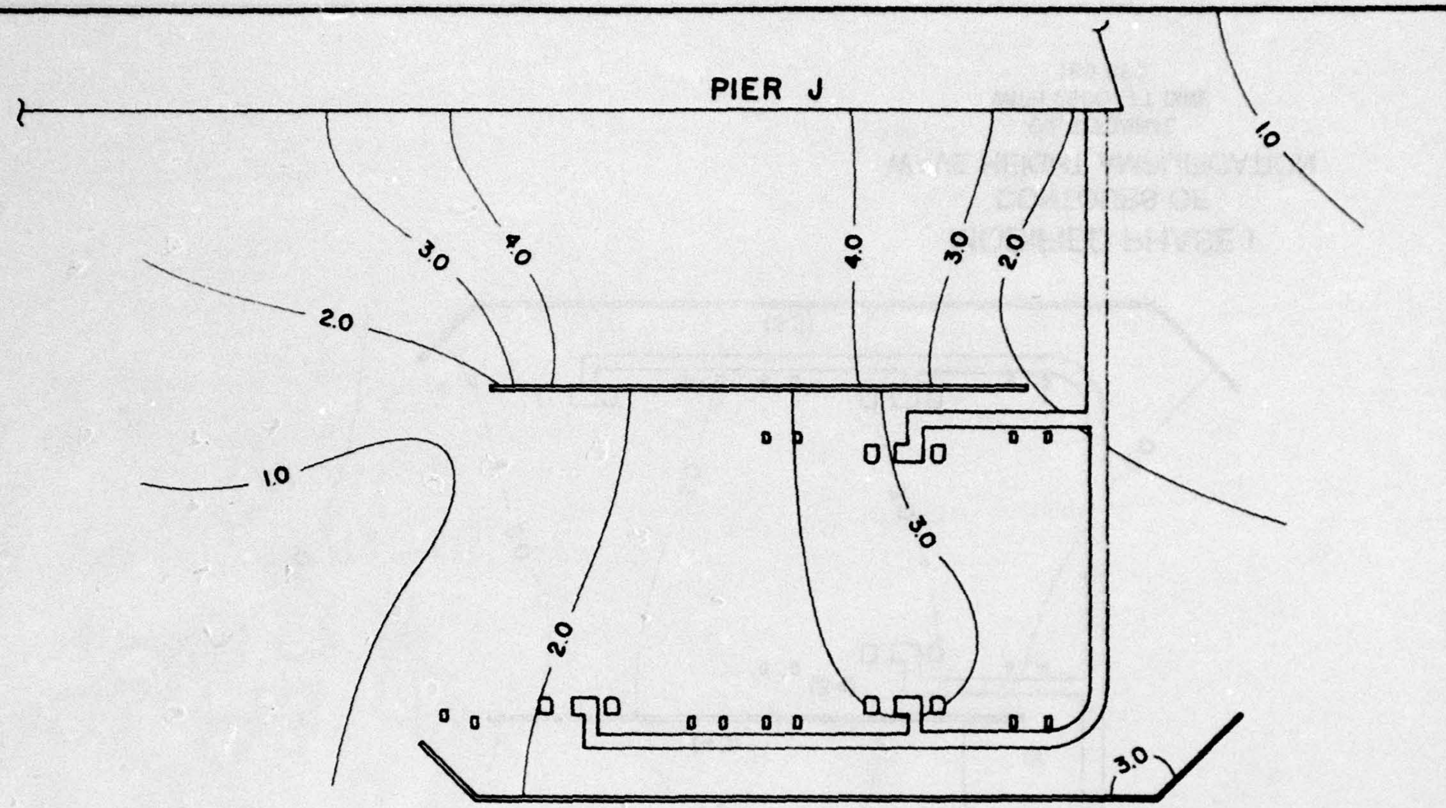
OIL TERMINAL
WITH 2000 FT DIKE
96 SEC



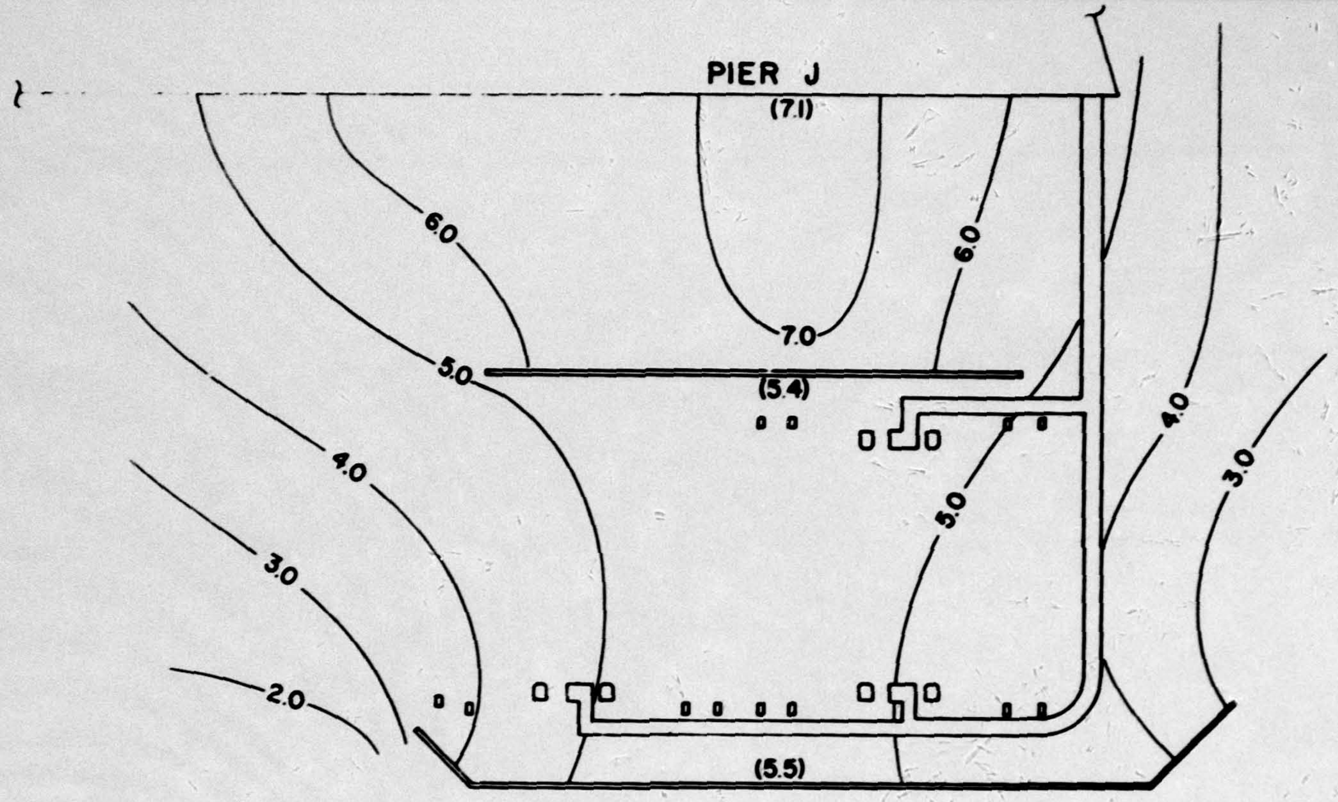
MODIFIED PHASE I
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
OIL TERMINAL
WITH 2000—FT DIKE
111 sec



MODIFIED PHASE I
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
OIL TERMINAL
WITH 2000—FT DIKE
169 SEC



MODIFIED PHASE I
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
OIL TERMINAL
WITH 2000—FT DIKE
183 SEC



MODIFIED PHASE I
CONTOURS OF
WAVE HEIGHT AMPLIFICATION
OIL TERMINAL
WITH 2000—FT DIKE
295 SEC

APPENDIX A: NOTATION

h_m	Model depth of the inner harbor
H_i	Incident wave height
H_m	Model wave height
H_r	Vertical scale ratio
H_s	Significant wave height
H_w^M	Model generated wave height
H_w^P	Prototype generated wave height
K_r	Refraction coefficient
$K_s^{M,G}$	Model shoaling coefficient at the gage locations
$K_s^{M,W}$	Model shoaling coefficient at the wave generator
$K_s^{P,A}$	Prototype shoaling coefficient at the initial refracted wave front
$K_s^{P,G}$	Prototype shoaling coefficient
$K_s^{P,W}$	Prototype shoaling coefficient at wave generator
ℓ_{hm}	Horizontal length scale in the model
ℓ_{hp}	Horizontal length scale in the prototype
L_m	Model wavelength
R	Wave-height amplification factor
T_m	Model wave period
T_p	Prototype wave period
Ω	Distortion

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Outlaw, Douglas G

Los Angeles and Long Beach Harbors model study; Report 6: Resonant response of the modified phase I plan / by Douglas G. Outlaw. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.

39, 3, 1 p., 91 leaves of plates : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; H-75-4, Report 6)

Prepared for U. S. Army Engineer District, Los Angeles, Los Angeles, Calif.

References: p. 39.

1. Harbor oscillations. 2. Harbors. 3. Hydraulic models. 4. Long Beach Harbor. 5. Los Angeles Harbor. 6. Water waves. I. United States. Army. Corps of Engineers. Los Angeles District. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; H-75-4, Report 6.

TA7.W34 no.H-75-4 Report 6